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An Evaluation of Application and Surface Preparation Parameters for Thermal Spray Coatings

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The U.S. Army Corps of Engineers uses thermal-sprayed zinc and aluminum coatings on hydraulic structures exposed to severe impact and abrasion damage caused by ice and floating debris. These coatings are also used widely for corrosion prevention on civil engineering structures across the nation. An experimental study of the twin-wire electric arc (TWEA) spraying of zinc and aluminum coatings was conducted to demonstrate the suitability of this technology for Army applications.

Experiments on six materials systems were conducted using classical and statistically designed fractional-factorial schemes. TWEA process parameters studied included current, spray angle, spray distance, and system pressure. A systematic design of experiments was utilized in order to display the range of processing conditions and their effect on the resultant coating. The coatings were characterized with bond strength and deposition efficiency tests, and optical metallography. Coating properties were quantified with respect to roughness, hardness, porosity, oxide content, bond strength, and microstructure. Coating performance was evaluated and quantified with erosion testing, and a parameter-property-performance relationship was developed for each materials system.

Foreword

This study was conducted for the Directorate of Civil Works, U.S. Army Corps of Engineers (USACE) under Civil Works Work Unit L18, "HPMS High Performance Paint Systems." The technical monitor was Andy Wu, CECW-EE.

The work was performed by Vartech, Inc, of Idaho Falls, ID, under contract to the Materials and Structures Branch (CF-M) of the Facilities Division (CF), U.S. Army Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Alfred D. Beitelman, CECER-CF-M. The experiments were conducted by Dominic. J. Varcalle, Jr. and Gary C. Wilson (Vartech), and Mahlon Wixson and Frank Rogers (Thermion, Inc.). Metals analysis was conducted by Ken Couch (Protech Labs), and mechanical testing was conducted by Sanjay Sampath (State University of New York at Stony Brook). Dr. Ilker R. Adiguzel is Chief, CECER-CF-M, and L. Michael Golish is Chief, CECER-CF.

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1.0 Introduction

An experimental study of the twin-wire electric arc (TWEA) spraying of zinc and aluminum coatings has been undertaken to demonstrate the suitability of the systems for Army applications. The Corps of Engineers currently uses zinc and aluminum coatings for use on hydraulic structures exposed to severe impact and abrasion damage caused by ice and floating debris. Experiments were conducted using classical and statistically designed fractional-factorial schemes. The TWEA process parameters varied included spray angle, current, spray distance, and system pressure. A systematic design of experiments was utilized in order to display the range of processing conditions and their effect on the resultant coating. The coatings were characterized with bond strength and deposition efficiency tests, and optical metallography. Coating properties are quantified with respect to roughness, hardness, porosity, oxide content, bond strength, and microstructure. Performance evaluation of the coatings is quantified with erosion testing. A parameter-property-performance relationship was developed for each material system.

Six material systems were investigated including 1/8" 85Zn/15Al, 3/16" 85Zn/15Al, 1/8" Al, 3/16" Al, 1/8" Zn, and 3/16" Zn. 21 characterization experiments and 8 bond strength experiments were conducted per system.

Zinc and aluminum coatings find widespread applications in the automotive, transportation, aerospace, and aircraft industries. The material systems are commonly used for anti-corrosion applications in the infrastructural industry. Smooth coatings with low porosity, low oxide content, and high bond strength are desired in most applications.

1.1 Program Objectives

The program objectives for this project were as follows:

1. Measure the effects of various application and surface preparation parameters on the performance of 85Zn/15Al coatings.

2. Compare the erosion resistance of the 85/15 coatings to other zinc and aluminum TWEA coatings. The research will be used to develop thermal spray process parameters and inspection criteria for Corps of Engineers thermal spray projects.

The program was directed toward the development of repeatable, enhanced TWEA coatings for applications for the Corps of Engineers. The program is investigating advanced material systems, materials processing methods, and the development of technology for increased reliability of coatings. The program incorporated statistical process control (SPC) techniques with the use of SDE methodologies, coating characterization, and coating performance evaluation.

Work conducted by Vartech for ACERL involved the following tasks:

1. Classical and parametric experimentation.
2. Coating characterization.
3. Coating performance evaluation.
4. Statistical analysis of results.
5. Determination of optimum process parameters.
6. Documentation of results.

2.0 TWEA Process

The key advantages of the twin-wire electric arc (i.e. TWEA) process are higher output and lower cost than other processes. The process can be traced back to 1914,[1] when Schoop and his colleague Bauerlin performed their initial experiments with electric heating wires.

In the process, two wires are brought together and an electric arc is struck between them. Typical DC voltages are between 20 and 35 volts with current ranging up to 350 amperes and in some cases more. Wire feedrate is governed by the system current. The arc developed between the two wires causes the wire tips to melt and superheat. An atomizing gas, typically air, is delivered to these two wires in such a way as to strip off small droplets of molten metal. In this way, kinetic energy is transferred to the droplets. Typical air flow rates range from 30 to 60 standard cubic feet per minute (i.e. scfm). It is not uncommon to spray

with either nitrogen or argon in an attempt to reduce the formation of oxides on the molten droplets. In general, any material which is electrically conductive and can be made into a wire can be sprayed with a TWEA device. Figure 1 illustrates the Thermion TWEA apparatus utilized in this study.

3.0 Coating Design Characteristics

The empirical studies were conducted to determine if zinc and aluminum coatings sprayed with a TWEA spray system could perform as abrasive corrosion resistant coatings for infrastructural and ACERL site-specific applications. Once a coating is put into service the coating performance factors are strongly controlled by the nature and extent of porosity and oxide content in the as-sprayed coating. In this study, the coating designs were based on the determination of the highest abrasion resistance, minimum porosity, minimum oxide content, maximum bond strength, highest deposition efficiency, and smoothest coatings that could be obtained with the process.

The selection of a thermal spray coating depends on the desired service life, environmental envelope, operating duty, and the maintenance and repair support provided during the life cycle. Zinc and aluminum are widely used as spray coatings for steel since they provide corrosion protection by several mechanisms. First is the physical barrier of having the coating on the substrate. Zinc and aluminum are more negative in electrochemical potential then steel.[2] Thus if a crack occurs in the coating, a galvanic couple is created between the zinc or aluminum coating and the steel. The coating will act as the anode, preferentially corroding rather than the steel and providing cathodic protection. As the coating reacts with the environment, the corrosion products (i.e. oxides) provide another barrier by limiting diffusion of moisture to the active surface.

4.0 Experimental Procedure

The twin-wire electric arc spray process was chosen for this application because it can produce high purity, low porosity coatings with

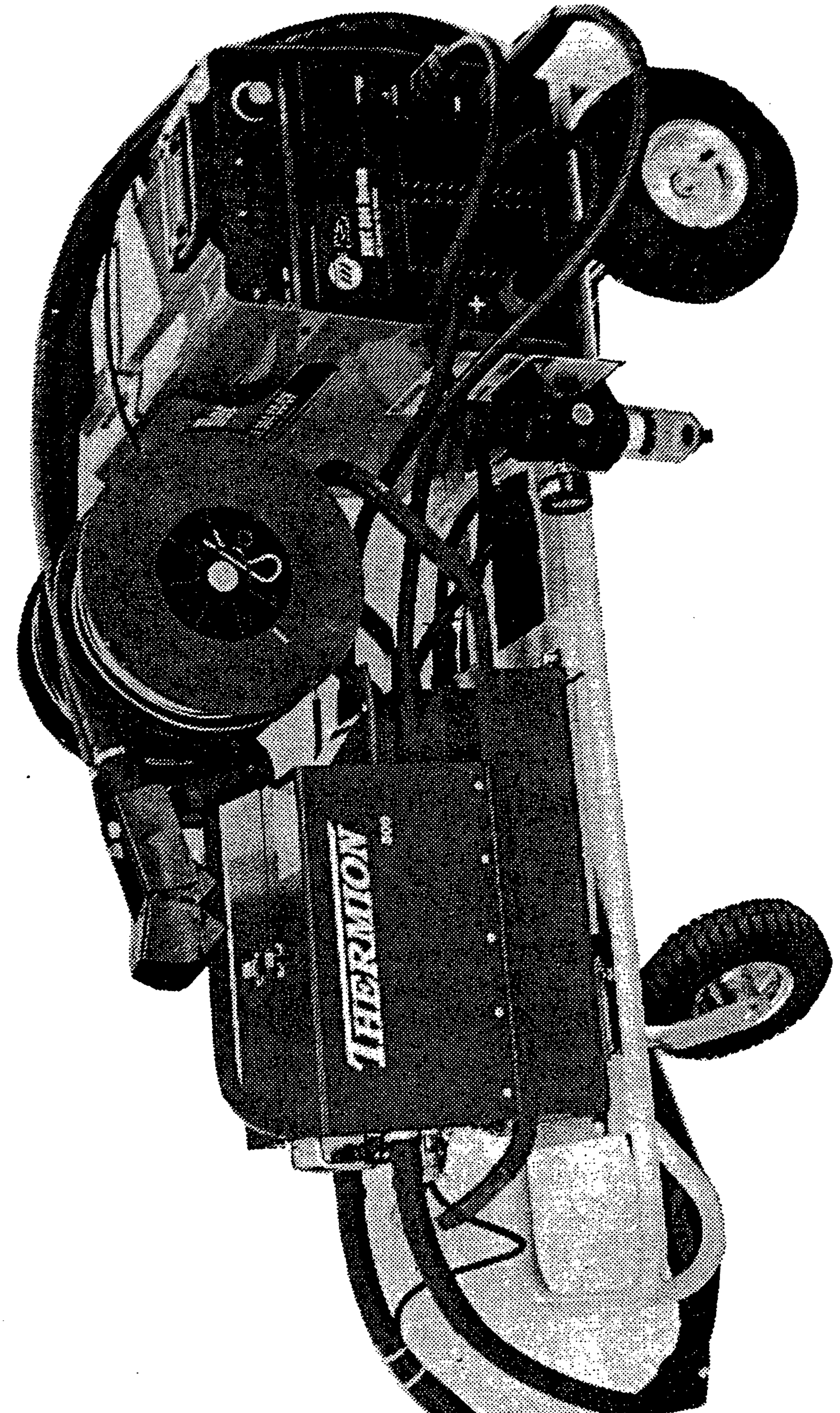

Figure 1. Thermion TWEA Apparatus

high bond and interparticle strength. A Thermion, Inc. TWEA spray system and commercially available wire were utilized. Box[3] type, fractional-factorial statistical design of experiments (i.e. SDE) and classical experiments were conducted for the six wire systems.

The Box analysis was accomplished with a commercial software package (i.e. Design-Expert[4]) on the measured responses. Table 1 represents the SDE design, which involves a 3 level fractional factorial experiment.

Table 1. TWEA SDE Coating Experiments

Exp	Spray Dist inches	Angle degrees	Current amps	Pressure psia
1	6.00	67.50	250.0	90.0
2	6.00	90.00	350.0	100.0
3	6.00	45.00	450.0	110.0
4	9.00	67.50	350.0	110.0
5	9.00	90.00	450.0	90.0
6	9.00	45.00	250.0	100.0
7	12.00	67.50	450.0	100.0
8	12.00	90.00	250.0	110.0
9	12.00	45.00	350.0	90.0
10	6.00	90.00	350.0	100.0
11	9.00	90.00	350.0	100.0
12	12.00	90.00	350.0	100.0
13	9.00	67.50	350.0	100.0
14	9.00	90.00	350.0	100.0
15	9.00	45.00	350.0	100.0
16	9.00	90.00	250.0	100.0
17	9.00	90.00	350.0	100.0
18	9.00	90.00	450.0	100.0
19	9.00	90.00	350.0	90.0
20	9.00	90.00	350.0	100.0
21	9.00	90.00	350.0	110.0

The process parameters varied in the SDE experiments included gun

pressure (P), current (A), spray distance (SD), and gun spray angle (SA). Nominal voltage was 29.5 volts for the 85/15 experiments, 31 volts for the aluminum experiments, and 30 volts for the zinc experiments. Air was used as the primary and shroud gas. Wire injection was internal to the gun and directed parallel to the flow. Wire feedrate varies proportionally with the system current and is shown in Table 2 for the six wire systems.

Table 2. Wire Feedrates (gr/min) for Coating Experiments

Material	250 Amps	350 Amps	400 Amps	450 Amps
1/8" 85/15	344	476	524	568
3/16" 85/15	484	580	668	732
1/8" aluminum	140	172	198	216
3/16" aluminum	192	264	280	288
1/8" zinc	432	628	688	776
3/16" zinc	640	792	852	1020

An x-y servo-manipulator ensured the standoff distance and repeatability in the experiments. The traverse x-motion rate was 16 inches per second. A y-step of 1.0 inch was used. The wire was thermal sprayed onto low carbon steel coupons which were cooled by air jets on the back side. The deposition side of each coupon was grit blasted with No. 36 alumina grit prior to spraying that surface. A maximum roughness (i.e. average amplitude) of 3 mils was obtained for the substrates for the coupons used for the met mounts and the abrasion testing. The substrate roughnesses were measured with Testex, Inc. profile replica tape and a KTA Tator micrometer.

Eight classical bond strength experiments per material system were also conducted as illustrated in Table 3.

5.0 Coating Characterization

Coatings were characterized and evaluated by a number of techniques for the six material systems. These include bond strength tests, optical metallography, image analysis, surface profilometry, and deposition

Table 3. TWEA Classical Bond Strength Coating Experiments and Results

Exp #	Blast media material	Blast profile mils	E BS psia	BE BS psia	A BS psia	BA BS psia	Z BS psia	BZ BS psia
B1	Al2O3	1	917	549	1059	713	407	407
B2	Al2O3	3	1304	1304	1896	1345	1080	876
B3	Cu slag	1	529	958	1427	611	549	509
B4	Cu slag	3	1427	1631	2202	1365	1080	1080
B5	Steel shot	1	101	81	488	345	61	20
B6	Steel shot	3	203	162	182	386	182	61
B7	Steel grit	1	978	978	1610	1338	774	767
B8	Steel grit	3	1257	1195	1556	1434	842	849

Notes: bond strength experiments spray parameters: spray distance: 9" for 1/8" 85/15 and zinc, 8" for all others; 90° spray angle; 350 amperes; 100 psia pressure.

efficiency. Characterization of the coatings yielded the physical, chemical, and mechanical properties of the various coatings including bond strength, roughness, porosity, oxide content, and deposition efficiency. Attributes were measured on metallographically prepared cross-sections of each coating. Tables 4a through 4f illustrates the result of the coating characterization and performance evaluation results.

Bond strength measurements were conducted for both the SDE experiments and the classical experiments illustrated in Table 3. The studies were conducted utilizing a portable adhesion tester (i.e. PATTI, Pneumatic Adhesion Tensile Testing Instrument) following the test procedure described by ASTM standard D4541. This methodology is reported to generate quantitative tensile strength data with a 2% or better accuracy. The materials were sprayed onto light carbon steel substrates. An adhesive was then used to bond a pull stub to the substrates. For the SDE experiments, each coupon was first grit blasted with No. 36 alumina grit prior to spraying that surface to obtain a surface roughness (i.e. amplitude) of 3 mils. The bond strength ranged from 734 to 1427 psia for the 1/8" 85/15 coatings, 1049 to 1437 psia for the 3/16" 85/15 coatings, 1417 to 2161 psia for the 1/8" aluminum coatings, 784 to 1356 psia for the

Table 4a. Characterization and Performance Evaluation Results for the 1/8" 85/15 (E) Wire System

Exp.	BS	Roughness	Porosity	Oxides	Hardness	CML
01	1212.0	17.39	6.00	4.300	50.00	0.0337
02	1264.0	11.52	1.90	1.300	41.80	0.0341
03	1427.0	11.55	9.60	4.000	50.90	0.0238
04	1284.0	10.19	4.60	4.100	47.50	0.0310
05	1386.0	16.46	4.80	2.300	41.10	0.0315
06	876.0	17.95	11.50	2.600	49.10	0.0321
07	734.0	12.62	7.40	3.800	50.80	0.0334
08	1161.0	10.58	3.70	2.500	50.50	0.0382
09	957.0	18.71	10.70	3.300	50.60	0.0375
10	1029.0	9.24	1.40	2.000	36.70	0.0349
11	1090.0	10.80	5.90	3.400	50.10	0.0323
12	1223.0	16.12	6.30	4.300	52.00	0.0345
13	1233.0	11.68	4.20	2.600	50.30	0.0293
14	1100.0	10.09	5.60	2.400	49.40	0.0362
15	784.0	16.30	9.90	3.400	50.40	0.0302
16	998.0	12.00	5.60	3.900	50.30	0.0347
17	1161.0	13.94	5.40	3.700	51.30	0.0312
18	1253.0	10.90	5.50	3.900	51.90	0.0349
19	1182.0	11.60	6.60	3.700	52.10	0.0314
20	1141.0	14.86	5.20	2.800	50.90	0.0351
21	1315.0	9.01	3.90	3.300	48.90	0.0295
Avg	1133.8	13.0	6.0	3.2	48.9	0.0328

Table 4b. Characterization and Performance Evaluation Results for the 3/16" 85/15 (BE) Wire System

Exp.	BS	Roughness	Porosity	Oxides	Hardness	CML
01	1335.0	15.96	6.70	2.600	50.20	0.0329
02	1294.0	8.80	1.80	1.600	38.20	0.0285
03	1315.0	26.82	21.20	2.300	49.90	0.0126
04	1406.0	14.93	6.00	3.600	41.00	0.0254
05	1437.0	10.82	1.40	2.100	48.50	0.0290
06	1376.0	23.44	14.70	3.600	49.50	0.0224
07	1223.0	16.11	10.00	2.300	51.70	0.0314
08	1080.0	17.09	9.10	4.200	48.00	0.0391
09	1141.0	23.02	16.00	3.400	51.20	0.0312
10	1315.0	8.56	1.60	1.600	37.10	0.0319
11	1162.0	15.26	8.20	3.200	48.90	0.0312
12	1223.0	14.05	8.50	3.500	49.80	0.0352
13	1223.0	14.04	7.40	2.500	47.50	0.0290
14	1049.0	12.01	6.10	2.700	50.00	0.0363
15	1171.0	19.37	12.80	4.200	48.80	0.0214
16	1141.0	12.54	5.60	3.700	47.70	0.0328
17	1212.0	10.51	5.50	3.000	48.90	0.0339
18	1335.0	12.66	4.00	3.400	47.60	0.0341
19	1213.0	14.13	3.30	3.600	40.40	0.0340
20	1294.0	13.03	3.40	3.400	46.00	0.0286
21	1192.0	10.15	4.30	3.400	48.90	0.0355
Avg	1244.6	14.9	7.5	3.0	47.1	0.0303

notes: roughness in microns, porosity in %, oxide content in %, bond strength (BS) in psi, cumulative mass loss (CML) in grams

Table 4c. Characterization and Performance Evaluation Results for the 1/8" Aluminum (A) Wire System

Exp.	BS	Roughness	Porosity	Oxides	Hardness	CML
01	1743.0	20.23	8.90	2.900	51.20	0.0503
02	1896.0	16.31	9.40	4.200	51.10	0.0515
03	1896.0	27.73	12.60	3.100	49.70	0.0559
04	1815.0	17.13	12.30	5.300	49.90	0.0466
05	2029.0	15.66	10.80	3.700	49.60	0.0477
06	1733.0	27.86	16.00	4.000	49.90	0.0642
07	1835.0	21.31	14.20	4.300	51.50	0.0628
08	1549.0	18.97	10.40	5.700	51.10	0.0591
09	1417.0	24.73	21.40	3.600	51.30	0.0479
10	2060.0	18.18	11.90	4.400	47.30	0.0510
11	2060.0	18.29	10.50	2.800	49.20	0.0655
12	1835.0	16.81	12.50	2.900	48.80	0.0535
13	1917.0	21.33	13.10	3.900	47.20	0.0448
14	2090.0	14.70	5.60	5.200	49.00	0.0606
15	1866.0	15.14	6.40	5.100	49.90	0.0245
16	1825.0	17.90	8.60	1.000	50.60	0.0709
17	1937.0	20.33	6.20	2.800	49.50	0.0603
18	2161.0	24.29	5.50	5.500	52.40	0.0498
19	1988.0	16.76	5.20	5.300	50.20	0.0551
20	1835.0	15.43	5.50	6.000	50.00	0.0588
21	2070.0	14.83	3.10	4.900	51.80	0.0507
Avg	1883.7	19.2	10.0	4.1	50.1	0.0539

Table 4d. Characterization and Performance Evaluation Results for the 3/16" Aluminum (BA) Wire System

Exp.	BS	Roughness	Porosity	Oxides	Hardness	CML
01	1294.0	17.41	5.10	6.600	44.80	0.0651
02	1039.0	15.22	1.90	2.700	45.20	0.0633
03	1213.0	26.44	4.40	5.300	44.00	0.0441
04	1049.0	18.04	8.30	7.100	48.60	0.0618
05	1356.0	18.36	9.70	9.400	53.00	0.0640
06	958.0	19.49	16.30	0.700	44.80	0.0746
07	836.0	19.11	8.00	4.600	48.20	0.0587
08	1100.0	19.45	10.40	1.000	46.90	0.0632
09	784.0	24.78	18.30	1.400	46.30	0.0132
10	1284.0	17.36	10.20	1.500	51.10	0.0681
11	1172.0	12.36	11.40	5.200	49.10	0.0806
12	1141.0	16.58	11.90	6.800	49.40	0.0549
13	917.0	16.93	13.30	5.500	49.30	0.0650
14	1110.0	14.35	6.50	2.300	48.50	0.0665
15	897.0	23.12	15.20	2.400	49.10	0.0158
16	1049.0	17.25	13.70	1.500	48.70	0.0482
17	1100.0	16.18	12.50	2.000	49.40	0.0576
18	1202.0	12.16	7.30	3.200	47.00	0.0694
19	1202.0	15.51	13.30	2.600	48.40	0.0739
20	1090.0	16.26	1.30	2.400	49.90	0.0589
21	1111.0	14.69	7.40	5.500	49.50	0.0758
Avg	1090.7	17.7	9.8	3.8	48.2	0.0592

notes: roughness in microns, porosity in %, oxide content in %, bond strength (BS) in psi, cumulative mass loss (CML) in grams

Table 4e. Characterization and Performance Evaluation Results for the 1/8" Zinc (Z) Wire System

Exp.	BS	Roughness	Porosity	Oxides	Hardness	CML
01	1223.0	11.57	1.40	2.000	24.40	0.0874
02	978.0	14.70	4.50	3.700	27.10	0.0804
03	917.0	14.37	7.40	4.900	28.20	0.0664
04	1008.0	13.91	4.60	2.400	29.90	0.0833
05	1059.0	15.77	2.80	1.400	24.30	0.0780
06	836.0	16.10	8.80	3.200	30.20	0.0872
07	876.0	15.13	6.20	3.900	26.30	0.0827
08	927.0	10.94	9.30	7.200	28.50	0.0739
09	713.0	18.18	16.80	6.900	33.10	0.1091
10	968.0	13.13	7.80	4.700	23.80	0.0449
11	958.0	12.39	7.90	7.900	31.10	0.0779
12	815.0	14.60	9.30	4.800	28.00	0.0784
13	937.0	13.16	12.60	3.600	31.20	0.0813
14	948.0	10.18	8.40	2.400	26.50	0.0849
15	743.0	18.74	10.30	2.700	29.40	0.1448
16	846.0	12.10	5.70	3.100	24.60	0.0952
17	937.0	10.63	12.10	6.800	32.40	0.0822
18	1100.0	8.91	1.20	1.600	22.40	0.0735
19	1100.0	12.37	7.00	1.700	25.40	0.0794
20	978.0	9.28	9.30	3.200	29.90	0.0822
21	1039.0	11.05	5.30	4.900	24.90	0.0828
Avg	947.9	13.2	7.6	4.0	27.7	0.0836

Table 4f. Characterization and Performance Evaluation Results for the 3/16" Zinc (BZ) Wire System

Exp.	BS	Roughness	Porosity	Oxides	Hardness	CML
01	1019.0	11.12	12.90	2.800	30.90	0.0656
02	998.0	14.84	11.90	0.500	34.60	0.0812
03	968.0	17.28	10.80	5.200	32.30	0.0494
04	937.0	13.21	10.50	3.400	31.00	0.0727
05	897.0	18.75	7.80	3.600	33.80	0.0802
06	785.0	14.40	9.70	3.400	31.90	0.0681
07	845.0	19.10	5.50	3.300	25.40	0.0686
08	815.0	14.65	10.20	2.300	31.20	0.0773
09	683.0	19.96	13.40	5.900	31.00	0.1018
10	1019.0	16.13	8.90	3.200	26.80	0.0767
11	968.0	13.43	10.70	3.800	32.90	0.0789
12	795.0	12.38	7.60	2.900	30.10	0.0662
13	825.0	18.07	5.30	1.900	30.70	0.0667
14	815.0	13.92	12.70	1.800	31.00	0.0729
15	734.0	22.18	10.60	2.700	30.60	0.0623
16	998.0	15.84	7.60	1.500	31.80	0.0581
17	846.0	21.13	13.30	2.200	29.80	0.0845
18	774.0	12.60	11.60	2.500	29.90	0.0787
19	907.0	17.69	19.70	2.800	31.80	0.0793
20	876.0	12.92	16.80	4.400	33.10	0.0790
21	1009.0	15.16	18.30	2.700	29.70	0.0734
Avg	881.6	15.9	11.2	3.0	31.0	0.0734

notes: roughness in microns, porosity in %, oxide content in %, bond strength (BS) in psi, cumulative mass loss (CML) in grams

3/16" coatings, 713 to 1223 psia for the 1/8" zinc coatings, and 683 to 1019 psia for the 3/16" coatings.

The classical bond strength experiments (B1 - B8) illustrated in Table 3 examined the effect of four blast media and two surface profiles. In general, for both 1/8" and 3/16" wire, the 3 mil profile exhibited higher bond strengths than the 1 mil profile. The aluminum coatings exhibited the highest bond strengths followed by the 85/15 coatings, and then the zinc coatings. The steel grit, copper slag, and alumina grit exhibited comparable bond strengths (i.e. within $\pm$ 200 psia), while the steel shot exhibited extremely low bond strengths.

Surface roughness was determined using a Surftest 301 roughness tester. The average roughness was calculated per ANSI standard B46.1 as the average departure y_i from the mean y. The average roughness ranged from 9.0 to 18.7 microns for the 1/8" 85/15 coatings, 8.6 to 26.8 microns for the 3/16" 85/15 coatings, 14.7 to 27.9 microns for the 1/8" aluminum coatings, 12.2 to 26.4 microns for the 3/16" aluminum coatings, 8.9 to 18.7 microns for the 1/8" zinc coatings, and 11.1 to 22.2 microns for the 3/16" zinc coatings.

Porosity was determined using image analysis (i.e. the differential interference contrast technique). A Leco 3001 Image Analyzer with an Olympus PMG-3 metallograph was used for the metallurgical mounts. A magnification of 500x was used to maximize contrast between the pores and the surrounding coating, and to obtain sufficient imaged pore size to ensure accuracy of results. Each coating was examined for bulk porosity at several locations and one representative area was chosen to determine the porosity for each coating. The porosities obtained from this methodology for each material are listed in the tables. The porosities of the 1/8" 85/15 coatings ranged from 1.4 to 11.5%, the 3/16" 85/15 coatings ranged from 1.4 to 21.2%, the 1/8" aluminum coatings ranged from 3.1 to 21.4%, the 3/16" aluminum coatings ranged from 1.3 to 18.3%, the 1/8" zinc coatings ranged from 1.2 to 16.8%, while the porosities of the 3/16" zinc coatings ranged from 5.3 to 19.7%.

The same image analysis procedure was used to measure oxide content. After the coatings were measured for porosity, the oxide content was obtained by simply subtracting the porosity value from the measured porosity

plus oxide value. The 1/8" 85/15 coatings ranged from 1.3 to 4.3%, the 3/16" 85/15 coatings ranged from 1.6 to 4.2%, the 1/8" aluminum coatings ranged from 1.0 to 6.0%, the 3/16" aluminum coatings ranged from 0.7 to 9.4%, the 1/8" zinc coatings ranged from 1.4 to 7.9%, and the 3/16" zinc coatings ranged from 0.5 to 5.9.

Vickers microhardness measurements were taken on the coatings perpendicular to the body of the coating. Ten measurements were taken and averaged using a 50 gram load. The microhardness measurements ranged from 36.7 to 52.1 for the 1/8" 85/15 coatings, 37.1 to 51.7 for the 3/16" 85/15 coatings, 47.2 to 52.4 for the 1/8" aluminum coatings, 44 to 53 for the 3/16" aluminum coatings, 22.4 to 33.1 for the 1/8" zinc coatings, and 25.4 to 34.6 for the 3/16" zinc coatings.

Deposition efficiency (DE) for the coatings was determined at four current levels with conventional techniques by measuring the amount of sprayed metal deposited for an allotted time on 12" by 12" plates. As illustrated in Table 5, the 3/16" aluminum (BA) and 3/16" zinc (BZ) systems showed a slight increase in DE with current, while the 3/16" 85/15 (BE) system showed a slight decrease. The 1/8" systems did not indicate any substantial effects. It is interesting to note that in all cases, the 3/16" wire exhibited higher DE than the 1/8" wire.

Table 5. Deposition Efficiency Experimental Results

Exp #	Current amperes	E DE %	BE DE %	A DE %	BA DE %	Z DE %	BZ DE %
DE1	250	64.0	70.7	64.3	68.8	57.9	62.0
DE2	350	63.9	71.0	66.3	72.8	58.0	64.8
DE3	400	61.8	67.7	61.2	77.1	57.9	64.0
DE4	450	64.8	63.7	62.0	77.1	53.6	67.5

Notes: DE experiments spray parameters: spray distance: 6 inches, 90° spray angle; 100 psia pressure.

Microstructures for all of the coatings of this study are illustrated in

the appendices (A: 1/8" 85/15 coatings, B: 3/16" 85/15 coatings, C: 1/8" aluminum coatings, D: 3/16" aluminum coatings, E: 1/8" zinc coatings, F: 3/16" zinc coatings).

Image analysis revealed differences in the microstructures for the experiments. Based on the criteria of either low CML or low porosity, the coatings vary substantially in quality. There are only minor differences between the microstructures of the 1/8" and 3/16" coatings.

All of the 85/15 photomicrographs indicate very dense coatings with homogenuously dispersed porosity. No cracking nor unmelted particles were evidenced in the body of any of the coatings. Figures A2 and B2 illustrate microstructures for coatings with very low porosity, very low oxide content, and intermediate CML. These coatings would be considered the best coatings of this study, if it were not for the fact that the coatings possess intermediate CMLs. Figures A3 and B3 illustrate microstructures for coatings with very high porosity and very low CML. These coatings were sprayed at drastic spray angles (45^{o}) which would not be practical in actual spraying. The A2 and B2 coatings have much smaller pores than the A3 and B3 coatings with more homogenuous distributions. The A3 and B3 coatings exhibited very large islands of porosity throughout the coatings. The splat morphologies are very similar for all of the coatings with a tendency for large diameter, thin lamellar structures.

The aluminum photomicrographs indicate very porous coatings (i.e. porosity average is 10%). The porosity is dispersed homogenuously throughout the coating matrices. No cracking nor unmelted particles were evidenced in the body of any of the coatings. Figures C2 and D2 illustrate microstructures for coatings with high porosity, intermediate oxide content, and intermediate CML. Figures C15 and D15 illustrate microstructures for coatings with very low CML. These coatings were sprayed at drastic spray angles (45^{o}) which would not be practical in actual spraying. The C2 and D2 coatings have much smaller pores than the C15 and D15 coatings with more homogenuous distributions. The C15 and D15 coatings exhibited very large islands of porosity throughout the coatings. The splat morphologies are very similar for all of the coatings with a tendency for small diameter, thick lamellar structures.

The zinc photomicrographs indicate coatings with intermediate porosity (i.e. porosity averages: Z = 7.6%, BZ = 11.2%). The porosity is dispersed homogenuously throughout the coating matrices. No cracking nor unmelted particles were evidenced in the body of any of the coatings. Figures E15 and F9 illustrate microstructures for coatings with high porosity, oxide content, and CML. Figures E10 and F3 illustrate microstructures for coatings with low CML and intermediate porosity. The E10 coating has the same size but less pores than the E15 coating. The F3 and F9 coatings exhibited very large islands of porosity throughout the coatings, with the F9 coating exhibiting more and larger pores.

5.1 Trend Analysis

Table 6 illustrates the trend analysis based on the coating characterization and performance evaluation results. Trends evidenced from the data indicate:

1. 85/15: higher porosity and roughness evidenced for larger wire; no effect on wire size for hardness, oxide content, CML, and bond strength.

2. Aluminum: lower bond strength and higher oxide content evidenced for larger wire; no effect on wire size for hardness, porosity, CML, and roughness.

3. Zinc: higher porosity, higher roughness, and lower CML evidenced for larger wire; small effect on wire size for bond strength; no effect on wire size for oxide content and hardness.

4. 85/15 vs aluminum: the 85/15 data indicates lower porosity and oxide content, lower bond strength and roughness, comparable hardness, and lower CML as compared to the aluminum data.

5. 85/15 vs zinc: the 85/15 data indicates lower porosity,

lower oxide content, substantially lower CML, higher hardness, higher bond strength, and comparable roughness as compared to the zinc data.

6. Zinc vs aluminum: the zinc data indicates lower hardness, lower bond strength, lower roughness, higher CML, and comparable porosity and oxide content relative to the aluminum data.

Table 6. Coating Trend Analysis

Wire	Porosity Avg/Range	Oxides Avg/Range	Hardness Avg/Range	Bond Strength Avg/Range	Roughness Avg/Range
E	6.0/1.4-11.5	3.2/1.3-4.3	48.9/36.7-52.1	1134/734-1427	13.0/9.0-18.7
BE	7.5/1.4-21.2	3.0/1.6-4.2	47.1/37.1-51.7	1245/1049-1437	14.9/8.6-26.8
A	10.0/3.1-21.4	4.1/1.0-6.0	50.1/47.2-52.4	1884/1417-2161	19.2/14.7-27.9
BA	9.8/1.3-18.3	3.8/0.7-9.4	48.2/44.0-53.0	1090/784-1356	17.7/12.1-26.4
Z	7.6/1.2-16.8	4.0/1.4-7.9	27.7/22.4-33.1	947/713-1223	13.2/8.9-18.7
BZ	11.2/5.3-19.7	3.0/0.5-5.9	31.0/25.4-34.6	882/683-1019	15.9/11.1-22.2

Wire	CML Avg/Range
E	0.0328/0.0238-0.0382
BE	0.0303/0.0126-0.0391
A	0.0539/0.0245-0.0709
BA	0.0592/0.0132-0.0806
Z	0.0836/0.0449-0.1448
BZ	0.0734/0.0494-0.1018

6.0 Coating Performance Evaluation

Laboratory testing of the coating samples was accomplished to evaluate the ability of the materials to resist erosion. Coating erosion resistance was measured in accordance with ASTM G-32. Samples 1 through 21 were tested for each material.

The cavitation evaluation procedure involved: 1. turning on the cooling water, 2. filling the beaker with distilled water, 3. scribing the specimen, 4. cleaning the specimen with acetone, 5. ultrasonic cleaning for 20 seconds, 6. blow off the sample with compressed air, 7. mount the sample to the tip using glue, 8. clean the residue, 9. ultrasonic cleaning with methanol for 30 seconds, 10. clean with compressed air, 11. reapply fresh methanol, 12. bake out at 120 ^{o}C for two minutes, 13. vacuum for 5 minutes, 14. record initial weight, 15. mount the specimen, 16. adjust tip to specimen distance to 1 mm, 17. start timer, 18. start cavitation experiment, 19. remove specimen from holder, 20. clean specimen with steps 9 through 13, 21. weight sample to determine weight loss.

Coupons were measured for cumulative mass loss (CML) at 1, 2, and 5 minutes. Results of the experimentation at 5 minutes are illustrated in Tables 4a through 4f. Trend analysis is illustrated in Table 6. At five minutes, the CML of the 1/8" 85/15 coatings ranged from 0.024 to 0.038 grams, while the CML of the 3/16" 85/15 coatings ranged from 0.0126 to 0.0391 grams. At five minutes, the CML of the 1/8" aluminum coatings ranged from 0.0245 to 0.0709 grams, while the CML of the 3/16" aluminum coatings ranged from 0.0132 to 0.0806 grams. At five minutes, the CML of the 1/8" zinc coatings ranged from 0.0449 to 0.1448 grams, while the CML of the 3/16" zinc coatings ranged from 0.0494 to 0.1018 grams. The lowest value of CML is the most abrasive resistant coating.

7.0 Discussion of Statistical Design of Experiments

In most experimental programs, a natural evolution occurs. In the early stages, classical screening experiments are conducted to identify potentially influential process parameters. In the middle stage, the experimenter knows which parameters influence the responses, but he requires a more quantitative understanding of the main effects, the possible interactions between the effects, and experimental error. In this stage, fractional-factorial and factorial designs are utilized. In the later stages of the experimentation, a thorough quantitative understanding of the effects of relatively few parameters is required and accomplished by the use of optimization (i.e. response surface) strategies. The relationship between the independent variables and the product response is fitted using

regression analysis techniques. In this study, all six of the coating designs have been optimized using this sequential methodology.

Statistically designed experiments were conducted for the six material systems to determine the parameter space for optimization. Table 1 represents the SDE design, which involves 3 level fractional factorial experiments for the characterization studies (12 experiments per material system for the SDE design and 10 centerpoint experiments). The SDE design constitutes a one-seventh replicate of 4 factors in 12 experiments. Each variable has three levels selected to band around the nominal settings in order to demonstrate the processing capabilities at a variety of stable processing conditions. Centerpoint experiments (i.e. 13 through 21) were also included to independently evaluate the process variation.

The Box-type statistical design of experiment methodology is an efficient means of determining broad-based factor effects on measured attributes. This methodology statistically delineates the impact of each variable on the measured coating characteristics across all combinations of other factors. By examination of the optimum levels of the process parameters a design coating can be obtained for the particular application.

8.0 Results of the Statistical Design of Experiments

8.1 Effects Analysis

Effects analysis was first conducted for the coating responses. For each response, the factor coefficients were calculated using least squares estimates. ANOVA (i.e. analysis of variance) analysis was then conducted to determine the adequacy of linear, quadratic, and cubic models. Once a model was chosen, each response was analyzed using the following methodology: the model was analyzed for an in-depth regression analysis, diagnostic evaluation of the robustness of the model was determined, and response surface analysis was conducted. Finally, the coating attributes were then numercially optimized.

In the effects analysis, the program first fits linear (main effects only, e.g. A), quadratic (linear effects plus square of main effects, and

two-factor interactions, e.g. A + A2 + AB), and cubic polynomials (quadratic effects plus cube of main effects and cubed interactions e.g. A2B and ABC) to the data. The ANOVA calculations provided a sequential comparison of models showing the statistical significance of adding the additional model terms to those terms already in the model. For the coating design, the cubic model was aliased in that there are not enough unique design points to estimate the coefficients. Thus, it was not considered in any of the response surface analysis. The quadratic regression model was chosen for all of the coating attributes for all six of the material systems to generate the regression equations.

Appendix A (Tables A1 - A6) illustrates the results of the statistical analysis for the 1/8" 85/15 coatings. Appendix B (Tables B1 - B6) illustrates the results of the analysis for the 3/16" 85/15 coatings. Appendix C (Tables C1 - C6) illustrates the results of the statistical analysis for the 1/8" aluminum coatings. Appendix D (Tables D1 - D6) illustrates the results of the analysis for the 3/16" aluminum coatings. Appendix E (Tables E1 - E6) illustrates the results of the statistical analysis for the 1/8" zinc coatings. Appendix F (Tables F1 - F6) illustrates the results of the analysis for the 3/16" zinc coatings.

In the effects analysis illustrated in the appendices, F values (i.e. the significance of adding terms to the model) were obtained for the linear, quadratic, and cubic models with corresponding probability values. A large F value and a small probability value indicate that adding the terms will improve the model.

ANOVA analysis, illustrated in the appendices, was conducted to determine the adequacy of the linear, quadratic, and cubic models indicated that the quadratic model was more effective for all of the measured coating attributes. The quadratic model yielded high F values (i.e. the comparison of the treatment variance with the error variance), low probability values (i.e. the probability that the model terms are not robust), and small coefficients of variations (i.e. indicating that the error was relatively small) for all of the quadratic analysis. These values indicate that the quadratic regression model was correct for each specific attribute.

The derived regression equations are illustrated in Appendices A through F. Equation 1 illustrates a typical equation for the porosity for the 1/8" 85/15 system (i.e. A = spray distance, B = spray angle, C = current, D = gun pressure). These equations define the process parameter-attribute relationship for each material.

Porosity 1/8" 85/15 = 143.3 +0.303*A -0.407*B -0.348*C -1.304*D -0.11*A2 +6.53E-03*B2 +7.04E-05*C2 +2.73E-03*D2 -4.17E-03*A*B +2.12E-03*A*C +2.13E-02*A*D +8.01E-05*B*C -5.77E-03*B*D +2.72E-03*C*D Equation 1

The diagnosis of residuals did not reveal any statistical problems in the regression analysis for any of the attributes (i.e. predicted is close to actual).

8.2 Process Parameter Perturbation Analysis

The perturbation plots for each attribute for each material system are illustrated in the appendices (Figures A22 - A27 for the 1/8" 85/15 coatings, Figures B22 - B27 for the 3/16" 85/15 coatings, Figures C22-C27 for the 1/8" aluminum coatings, Figures D22-D27 for the 3/16" aluminum coatings, Figures E22-E27 for the 1/8" zinc coatings, and Figures F22-F27 for the 3/16" zinc coatings). These plots illustrate the effect of each process parameter on the coating attribute and were used to determine the optimum coatings for this study. The optimum coating for this application would have in order of priority: low CML, low porosity, low oxides, high BS, low roughness, and high microhardness. Tables 7 through 12 illustrate the trends from this analysis, indicating the qualitative effect (i.e. 1=largest, 4=smallest) of each process parameter (i.e. factor) on the particular coating attribute (i.e. response), the total variance for each coating attribute, and the level that each process parameter should be used to optimize the specific coating attribute.

As illustrated in Table 7 for the 1/8" 85/15 coatings, CML, porosity, and bond strength are most strongly affected by spray angle, oxide content, roughness and microhardness are most strongly affected by spray distance.

Table 7. Results of the Parameter Effects Analysis for 1/8" 85/15

Processing Factor: Attrib/Tot. Variance	Process Parameters: Spray Dist A eff/Lev	Spray Angle B eff/Lev	Current C eff/Lev	Pressure D eff/Lev
1 Low CML/0.0144	3/0	1/-1	4/0	2/+1
2 Low Porosity/10.1	2/-1	1/-1	4/0	3/+1
3 Low Oxides/3.0	1/-1	2/-1	4/0	3/0
4 High Bond Stren/693	4/+1	1/-1	2/+1	3/+1
5 Low Roughness/9.7	1/-1	2/0	4/+1	3/+1
6 High Microhard/15.4	1/+1	3/+1	4/+1	2/-1

As illustrated in Table 8 for the 3/16" 85/15 coatings, CML, oxide content, and bond strength are most strongly affected by spray angle, while porosity, roughness and microhardness are most strongly affected by spray distance. There is excellent correlation between the two 85/15 wire systems in terms of effects analysis, in that all the responses are strongly affected by either spray distance and/or spray angle.

Table 8. Results of the Parameter Effects Analysis for 3/16" 85/15

Processing Factor: Attrib/Tot. Variance	Process Parameters: Spray Dist A eff/Lev	Spray Angle B eff/Lev	Current C eff/Lev	Pressure D eff/Lev
1 Low CML/0.0265	2/-1	1/-1	3/-1	4/-1
2 Low Porosity/15.1	1/-1	2/0	3/0	4/-1
3 Low Oxides/2.6	2/-1	1/-1	3/+1	4/0
4 High Bond Stren/388	3/-1	1/-1	2/+1	4/-1
5 Low Roughness/18.3	1/-1	3/0	4/0	2/+1
6 High Microhard/14.6	1/+1	4/-1	3/+1	2/+1

As illustrated in Table 9 for the 1/8" aluminum coatings, porosity,bond strength, roughness, and microhardness are most strongly affected by spray angle, while CML is most strongly affected by current, and oxide content by spray distance.

Table 9. Results of the Parameter Effects Analysis for 1/8" Aluminum

Processing Factor: Attrib/Tot. Variance	Spray Dist A eff/Lev	Spray Angle B eff/Lev	Current C eff/Lev	Pressure D eff/Lev
	<---------------	Process Parameters	----------------	-->
1 Low CML/0.05	3/-1	2/-1	1/0	4/+1
2 Low Porosity/18.3	2/0	1/+1	3/+1	4/+1
3 Low Oxides/5.0	1/+1	2/-1	1/-1	4/0
4 High Bond Stren/744	3/0	1/+1	2/+1	4/+1
5 Low Roughness/13.2	4/0	1/+1	2/0	3/+1
6 High Microhard/5.4	4/0	1/+1	2/+1	3/+1

As illustrated in Table 10 for the 3/16" aluminum coatings, porosity, CML, roughness and microhardness are most strongly affected by current, while oxide content and bond strength are most strongly affected by spray angle. The strong dependency on current for the 3/16" wire system in terms of effects analysis indicates that a completely different wire melting mechanism is occuring because of the larger wire.

Table 10. Results of the Parameter Effects Analysis for 3/16" Aluminum

Processing Factor: Attrib/Tot. Variance	Spray Dist A eff/Lev	Spray Angle B eff/Lev	Current C eff/Lev	Pressure D eff/Lev
	<---------------	Process Parameters	----------------	-->
1 Low CML/0.07	4/0	2/0	1/-1	3/0
2 Low Porosity/17.0	4/-1	3/+1	1/+1	2/+1
3 Low Oxides/8.7	3/-1	1/+1	2/-1	4/0
4 High Bond Stren/572	4/-1	1/+1	2/+1	3/-1
5 Low Roughness/14.3	3/0	2/0	1/+1	4/0
6 High Microhard/9.0	3/0	4/-1	1/0	2/+1

As illustrated in Table 11 for the 1/8" zinc coatings porosity, CML, and microhardness are most strongly affected by spray angle, while bond strength and roughness are most strongly affected by current. All of the responses are secondarily affected by spray distance.

Table 11. Results of the Parameter Effects Analysis for 1/8" Zinc

Processing Factor: Attrib/Tot. Variance	Spray Dist A eff/Lev	Spray Angle B eff/Lev	Current C eff/Lev	Pressure D eff/Lev
	<--------------	Process Parameters	----------------	>
1 Low CML/0.1	2/-1	1/-1	3/+1	4/-1
2 Low Porosity/15.6	2/-1	1/+1	3/+1	4/+1
3 Low Oxides/6.5	2/0	4/-1	3/+1	1/-1
4 High Bond Stren/510	3/-1	4/0	1/+1	2/-1
5 Low Roughness/9.8	2/0	3/0	1/+1	4/+1
6 High Microhard/10.7	2/+1	1/-1	3/0	4/0

As illustrated in Table 12 for the 3/16" zinc coatings, porosity and roughness are most strongly affected by spray angle, while oxide content is most strongly affected by spray distance, bond strength and CML are most strongly affected by current, and hardness is most strongly affected by pressure. Only porosity and bond strength show correlation with the 1/8" zinc system.

Table 12. Results of the Parameter Effects Analysis for 3/16" Zinc

Processing Factor: Attrib/Tot. Variance	Spray Dist A eff/Lev	Spray Angle B eff/Lev	Current C eff/Lev	Pressure D eff/Lev
	<--------------	Process Parameters	----------------	>
1 Low CML/0.0524	2/+1	4/-1	1/-1	3/0
2 Low Porosity/14.4	3/-1	1/-1	4/-1	2/0
3 Low Oxides/5.4	1/-1	4/-1	2/-1	3/0
4 High Bond Stren/336	2/-1	3/+1	1/-1	4/+1
5 Low Roughness/11.1	2/+1	1/0	3/+1	4/+1
6 High Microhard/9.2	4/0	3/-1	2/-1	1/-1

Figures 2 through 7 (1/8" 85/15), 8 through 13 (3/16" 85/15), 14 through 19 (1/8" aluminum), 20 through 25 (3/16" aluminum), 26 through 31 (1/8" zinc), and 32 through 37 (3/16" zinc) illustrate the response surface plots of the predicted values using the regression equations for the respective responses for the six coating systems. In these figures spray angle is held constant at 90^{o}, the preferred spray angle in most spraying operations. A second constant utilized the factor with the least affect on the response. This factor was set at the optimized level for

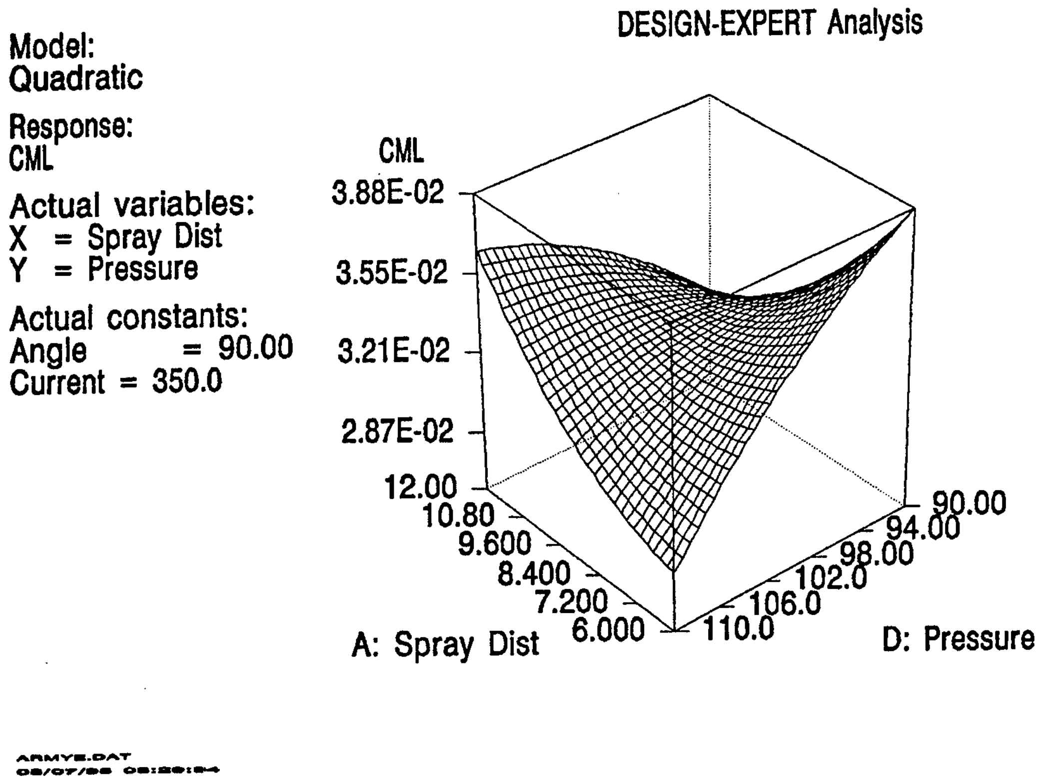

Figure 2. Response Surface Plot of CML for 1/8" 85/15

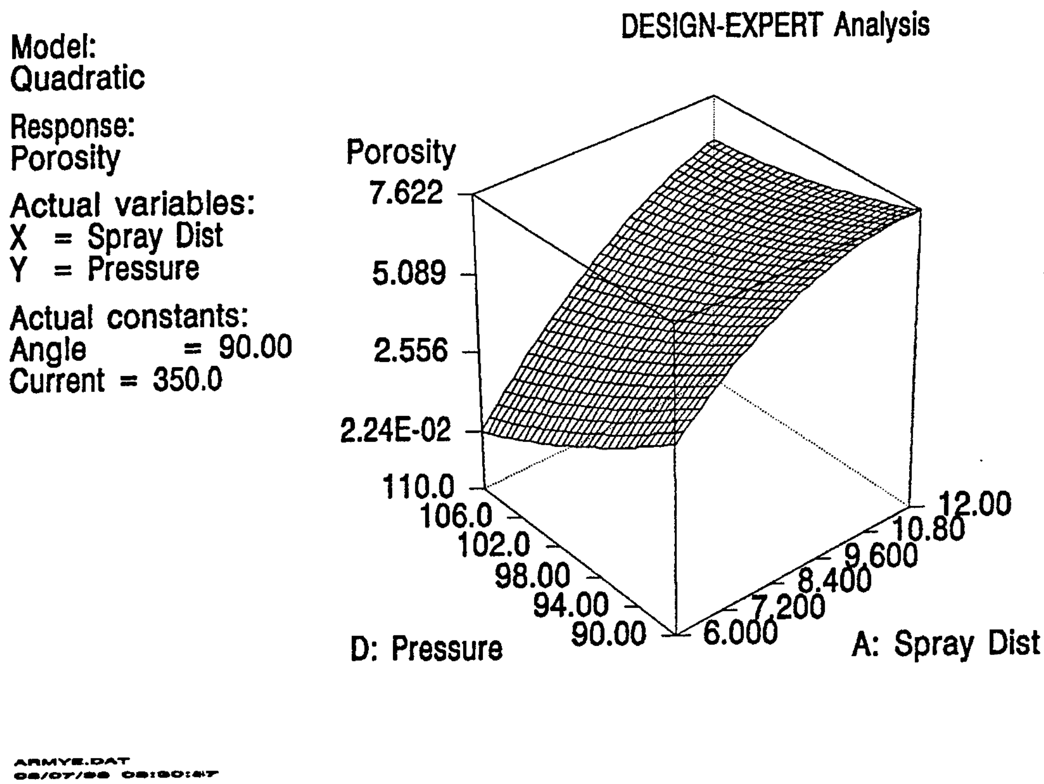

Figure 3. Response Surface Plot of Porosity for 1/8" 85/15

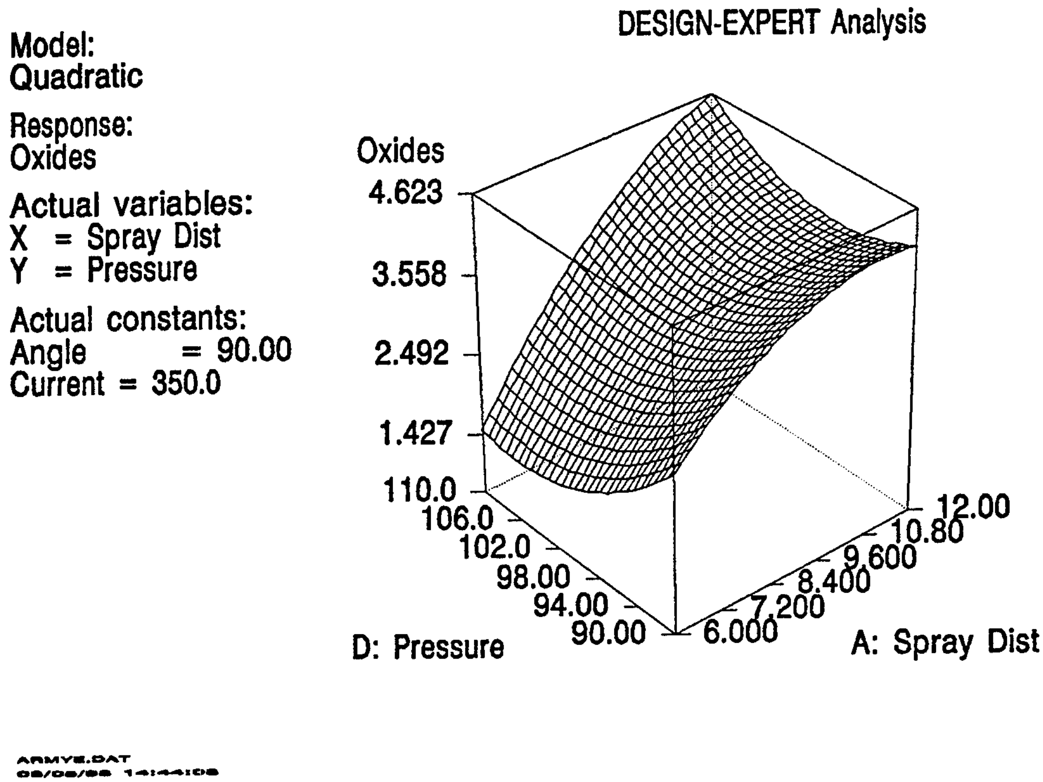

Figure 4. Response Surface Plot of Oxide Content for 1/8" 85/15

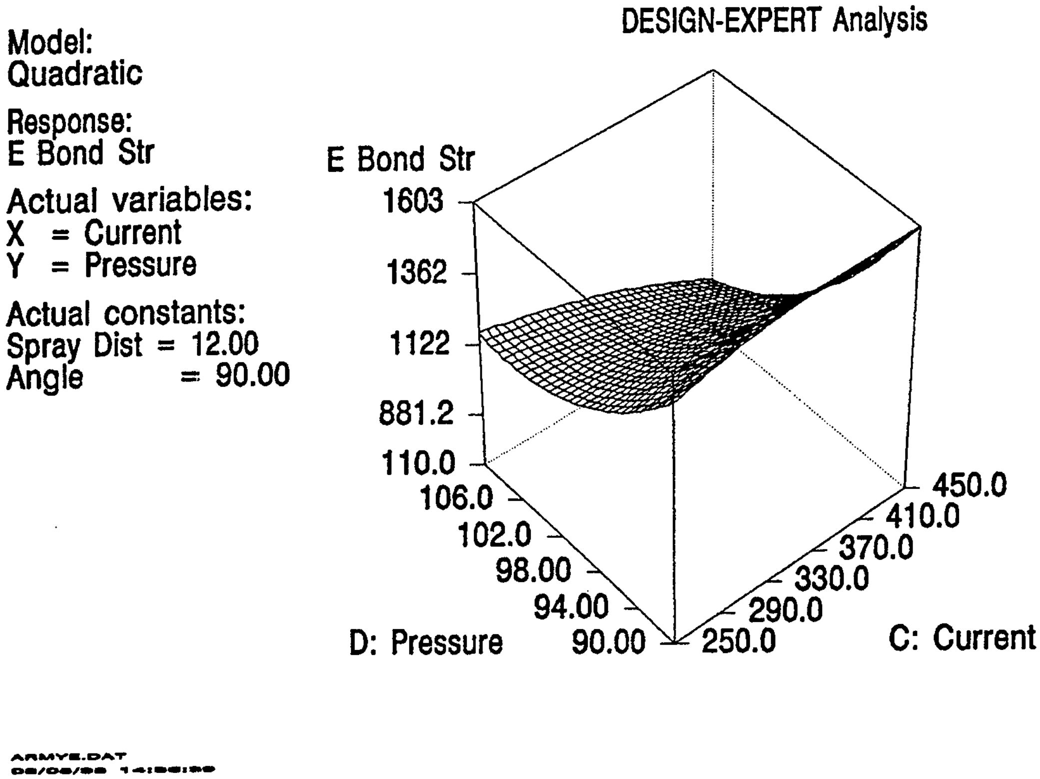

Figure 5. Response Surface Plot of Bond Strength for 1/8" 85/15

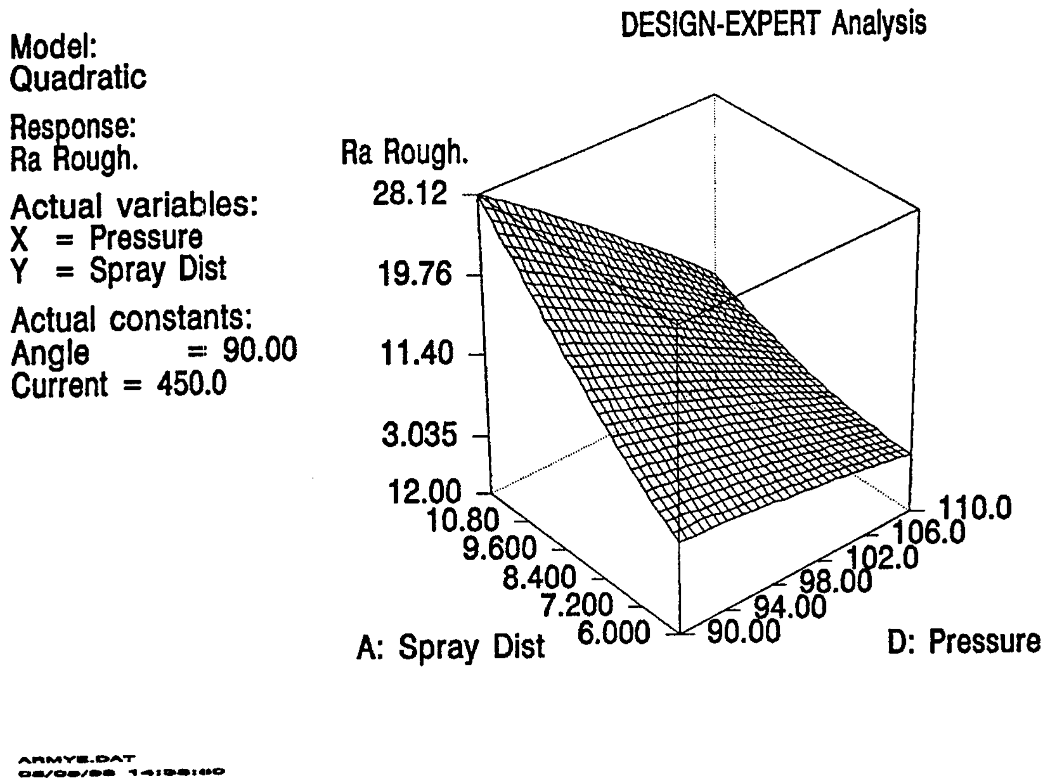

Figure 6. Response Surface Plot of Roughness for 1/8" 85/15

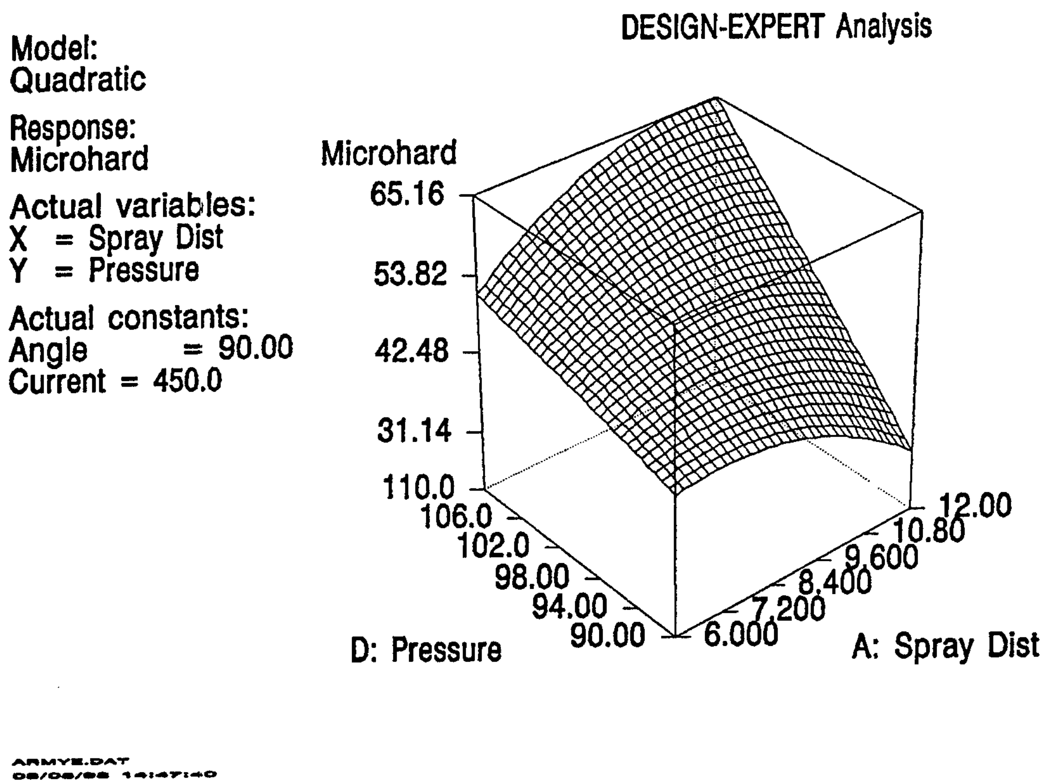

Figure 7. Response Surface Plot of Microhardness for 1/8" 85/15

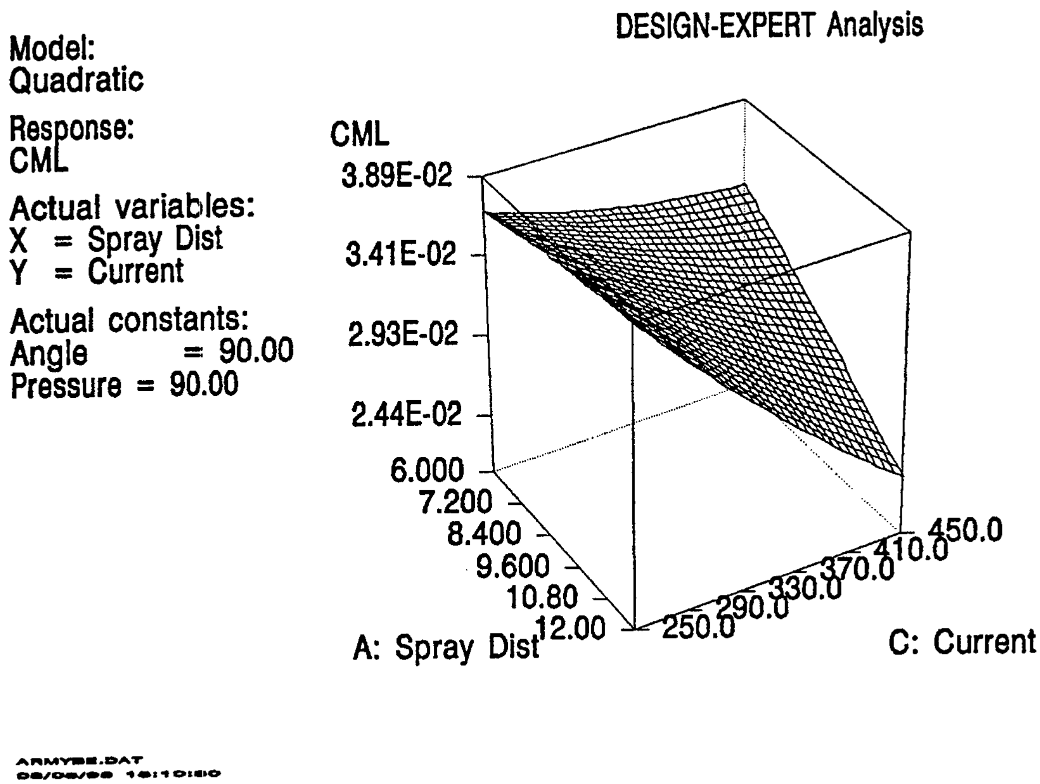

Figure 8. Response Surface Plot of CML for 3/16" 85/15

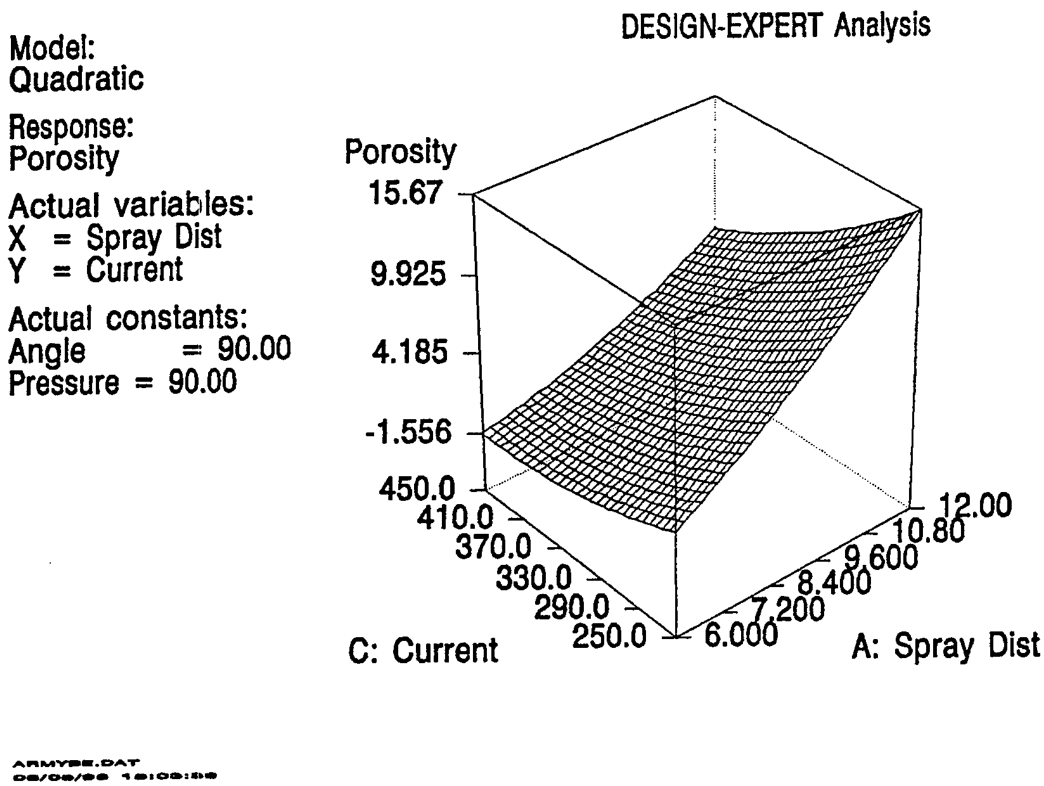

Figure 9. Response Surface Plot of Porosity for 3/16" 85/15

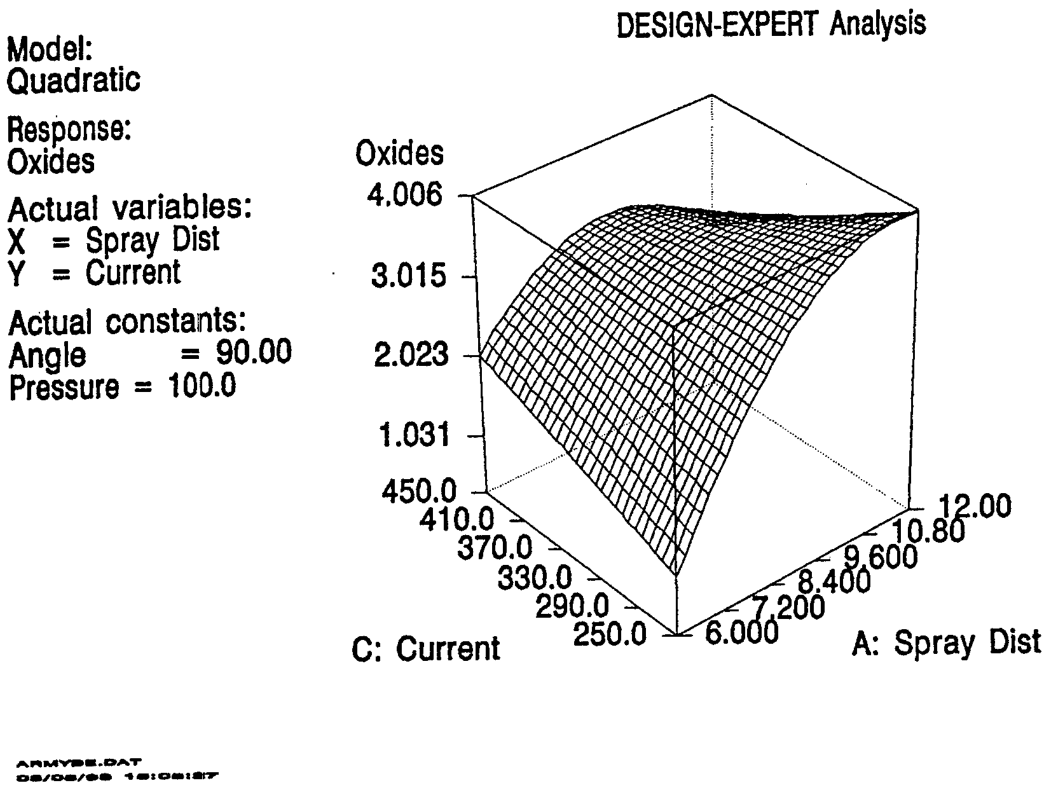

Figure 10. Response Surface Plot of Oxide Content for 3/16" 85/15

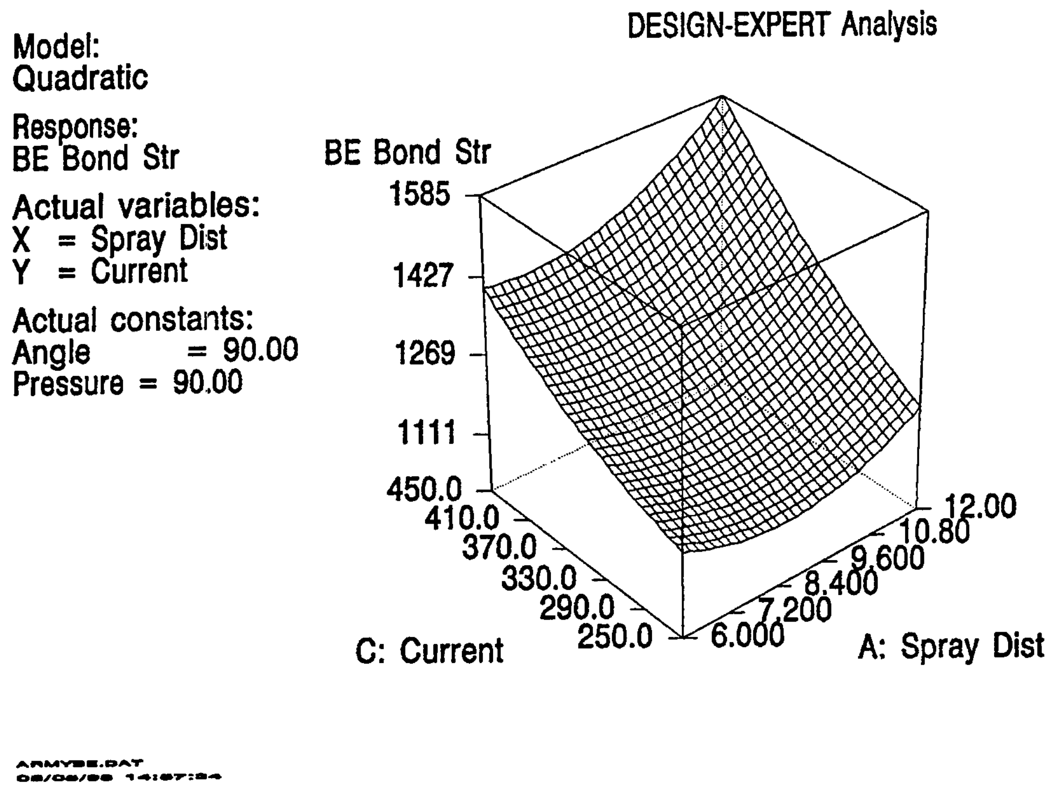

Figure 11. Response Surface Plot of Bond Strength for 3/16" 85/15

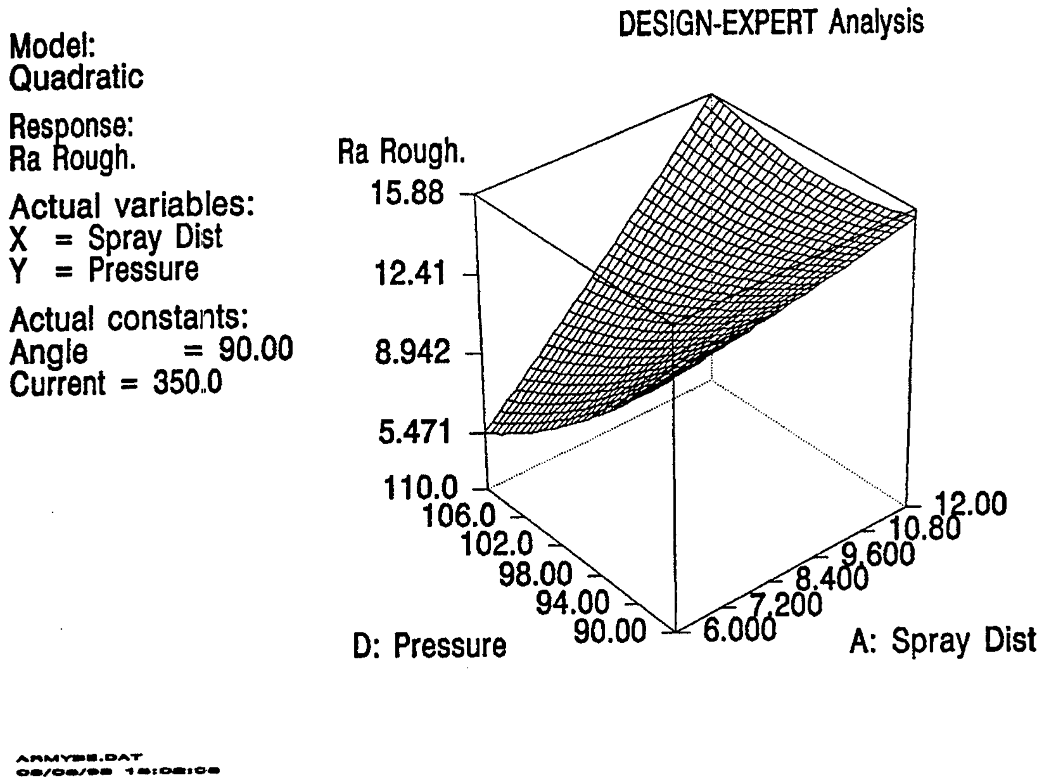

Figure 12. Response Surface Plot of Roughness for 3/16" 85/15

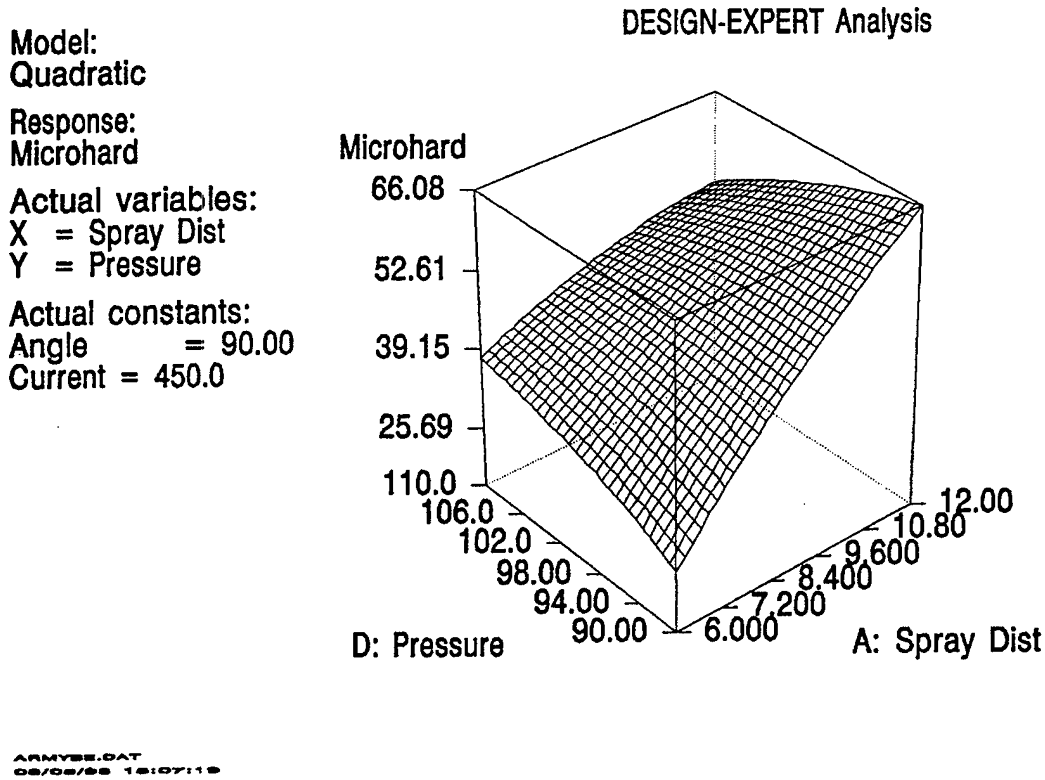

Figure 13. Response Surface Plot of Microhardness for 3/16" 85/15

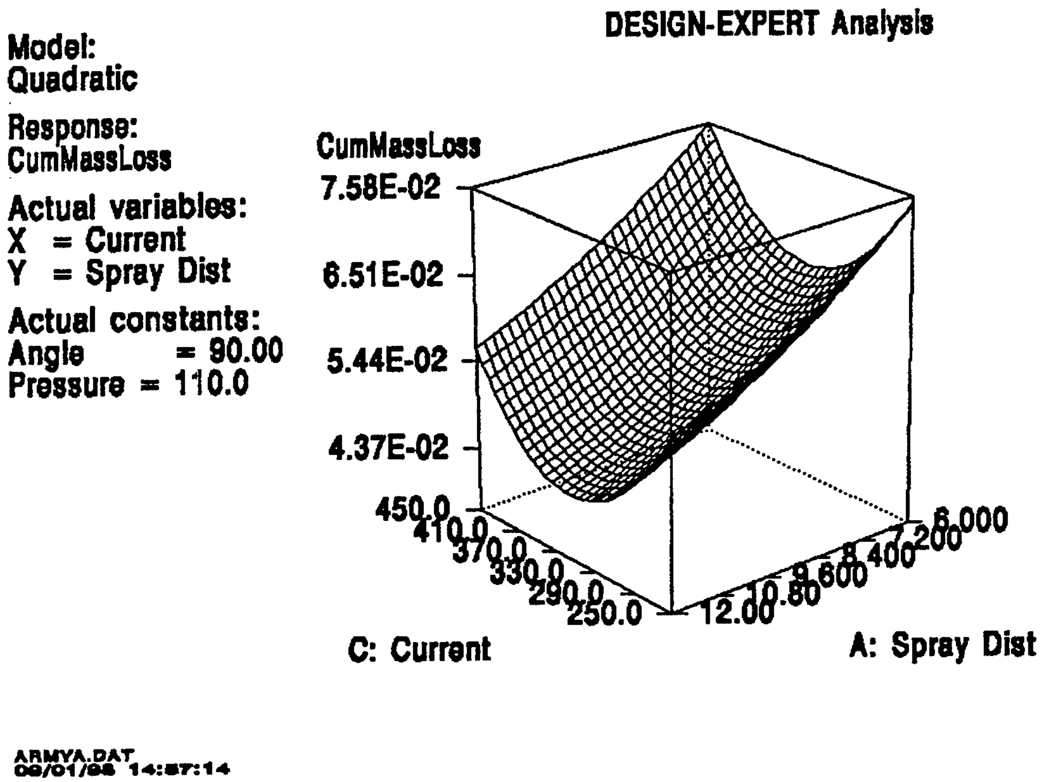

Figure 14. Response Surface Plot of CML for 1/8" Aluminum

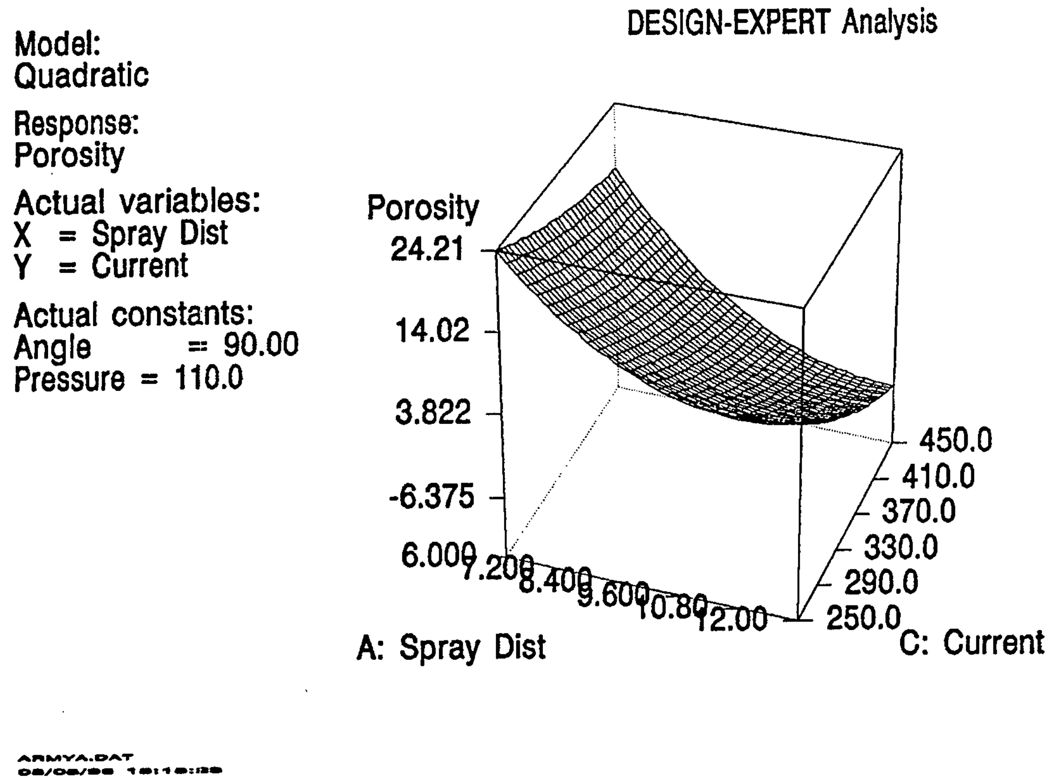

Figure 15. Response Surface Plot of Porosity for 1/8" Aluminum

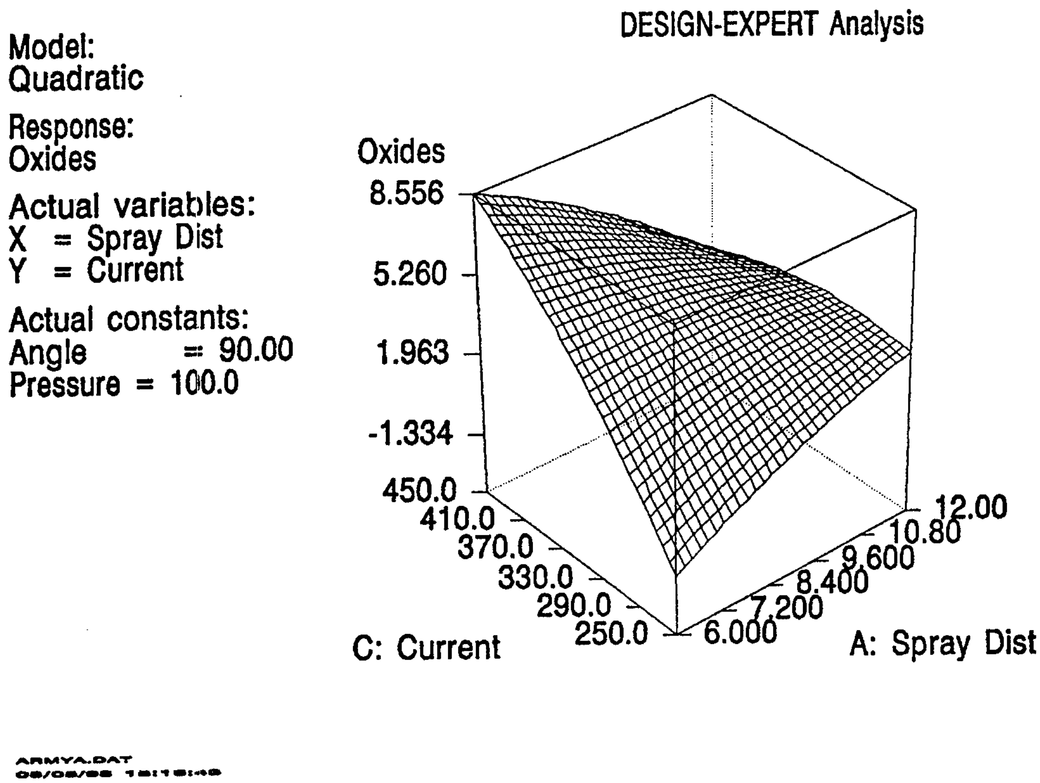

Figure 16. Response Surface Plot of Oxide Content for 1/8" Aluminum

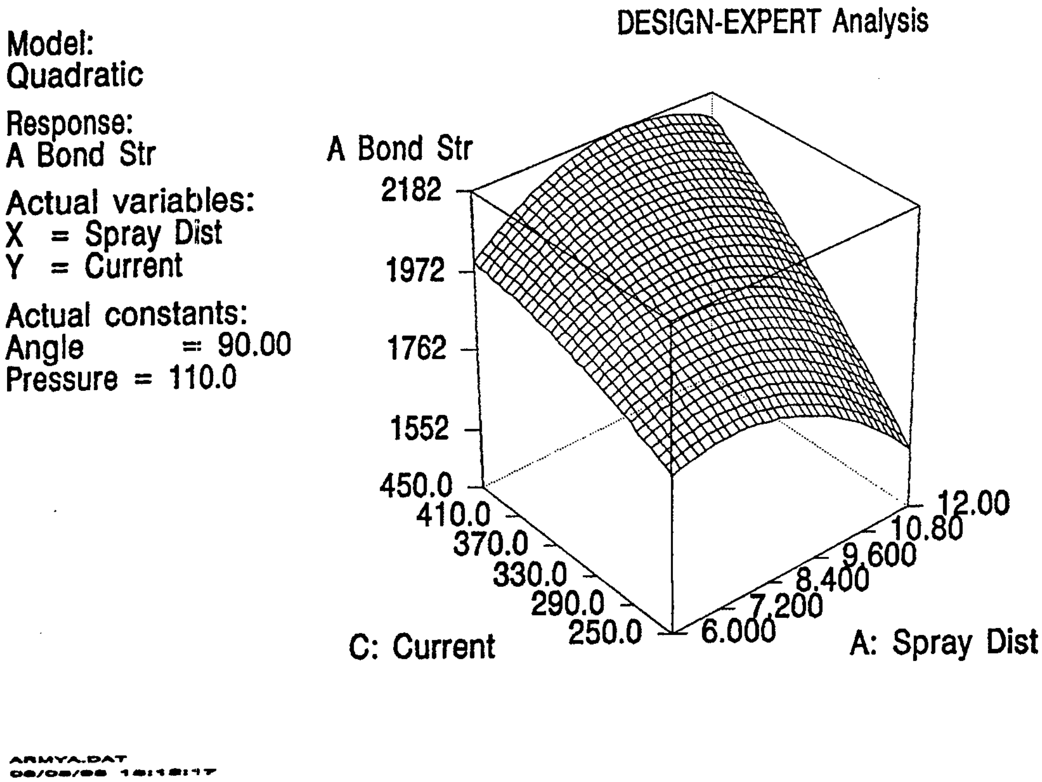

Figure 17. Response Surface Plot of Bond Strength for 1/8" Aluminum

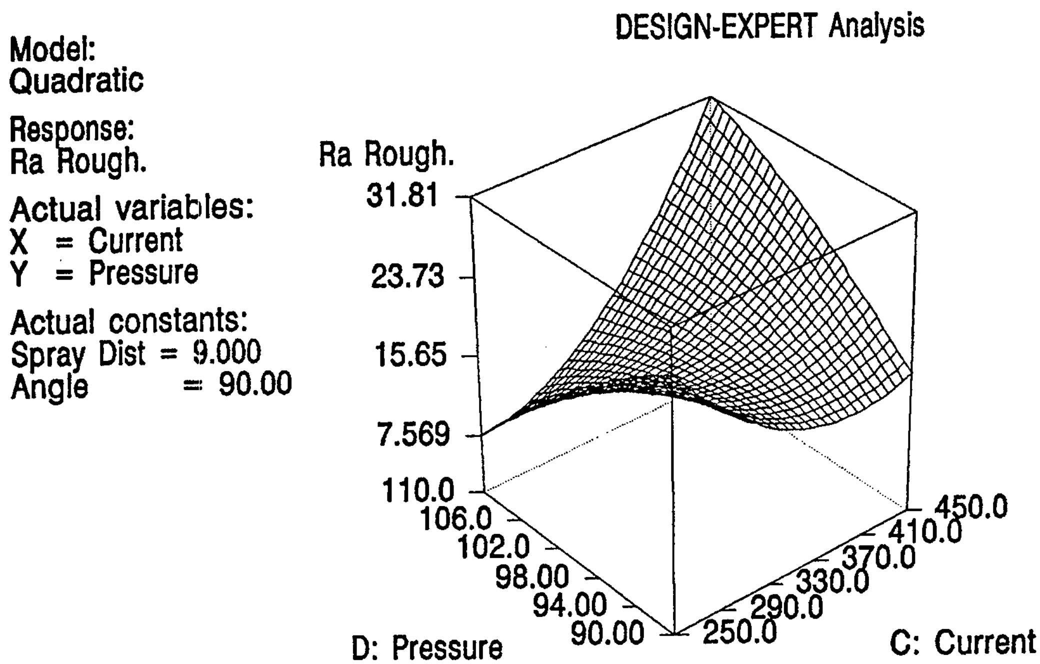

Figure 18. Response Surface Plot of Roughness for 1/8" Aluminum

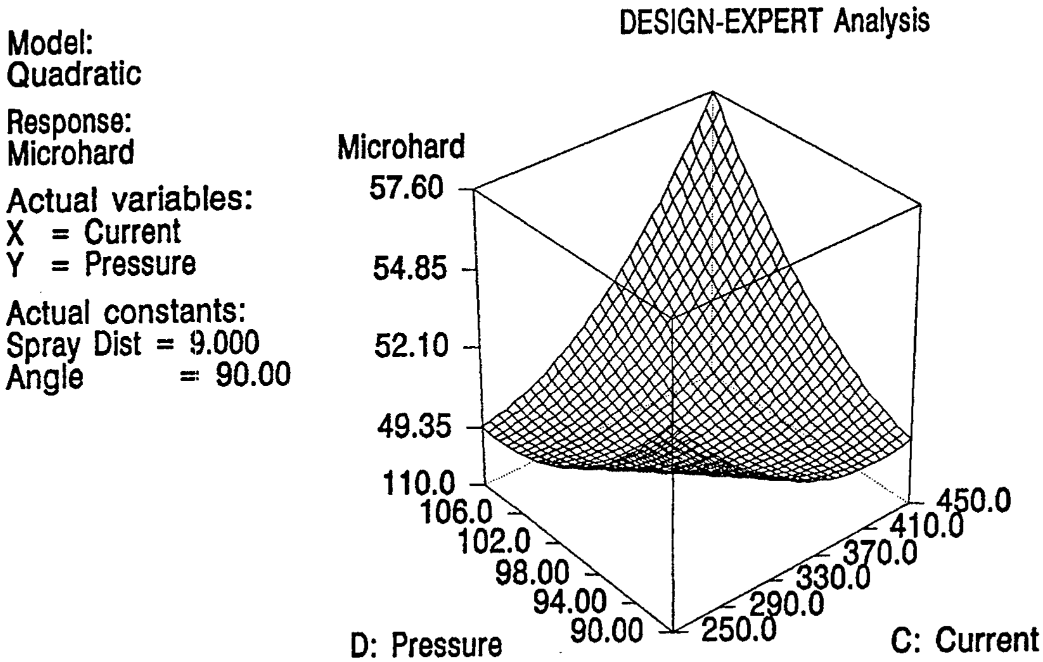

Figure 19. Response Surface Plot of Microhardness for 1/8" Aluminum

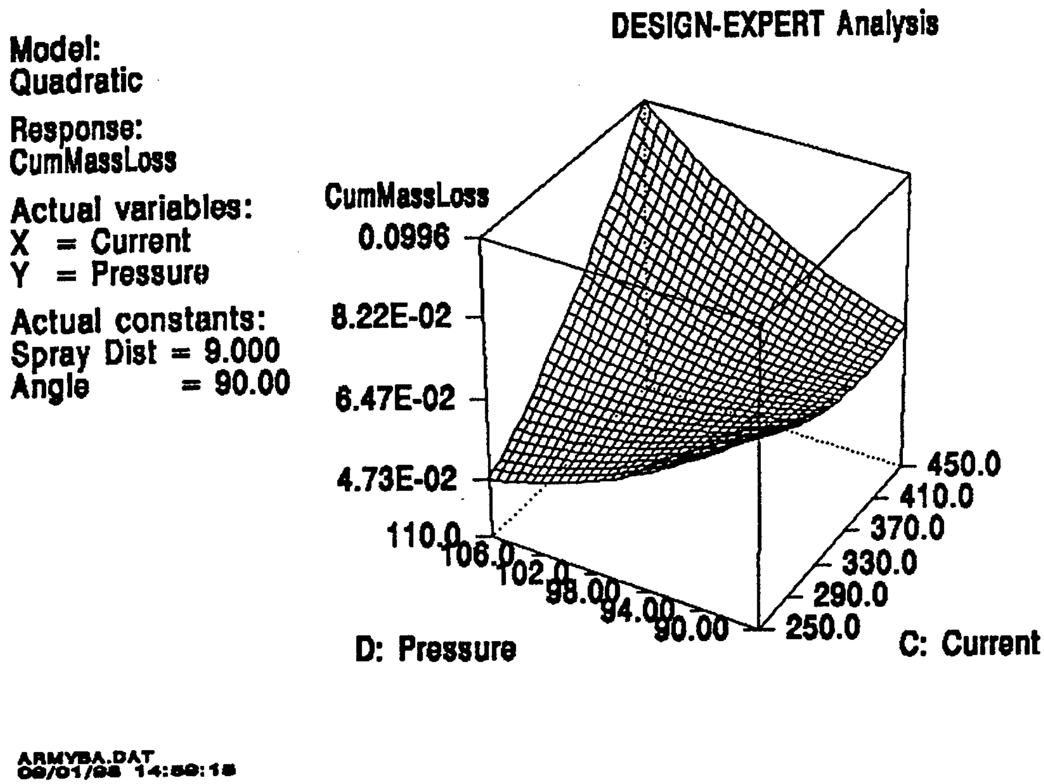

Figure 20. Response Surface Plot of CML for 3/16" Aluminum

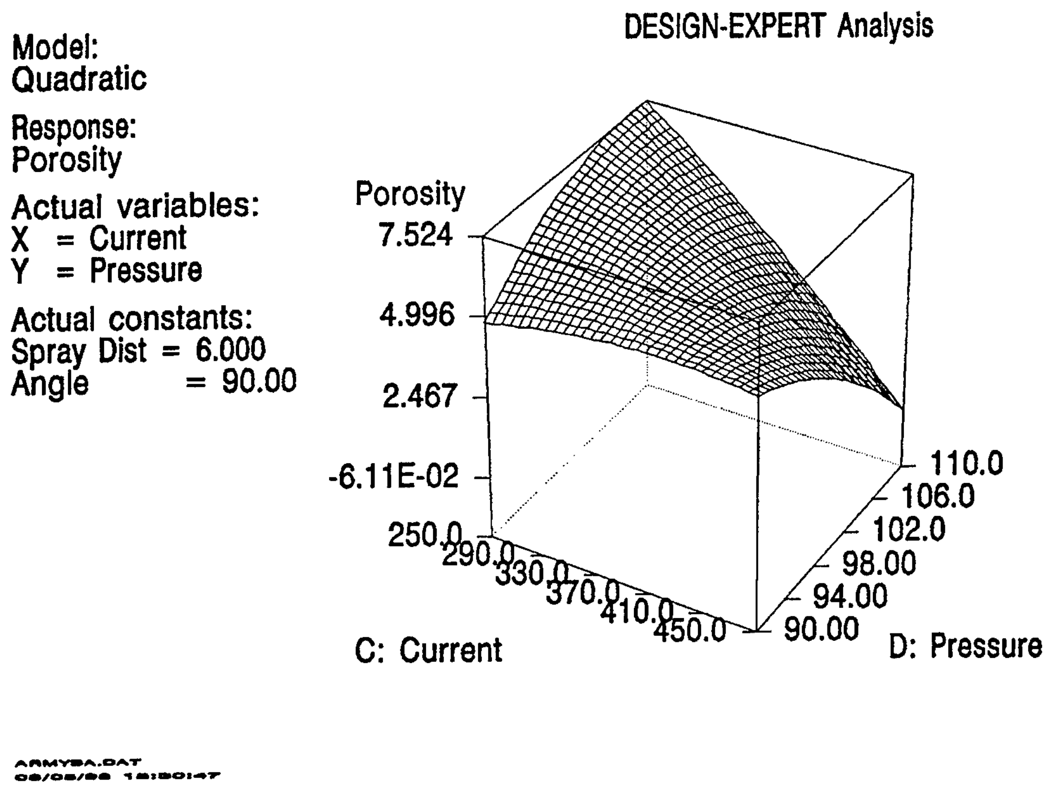

Figure 21. Response Surface Plot of Porosity for 3/16" Aluminum

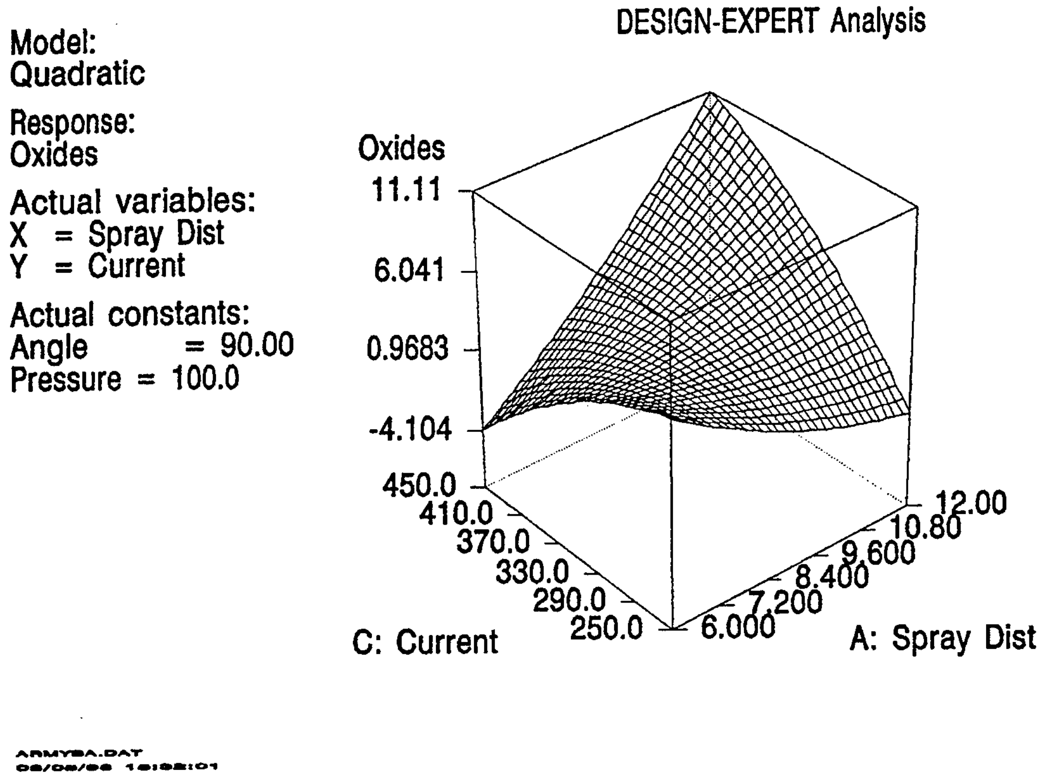

Figure 22. Response Surface Plot of Oxide Content for 3/16" Aluminum

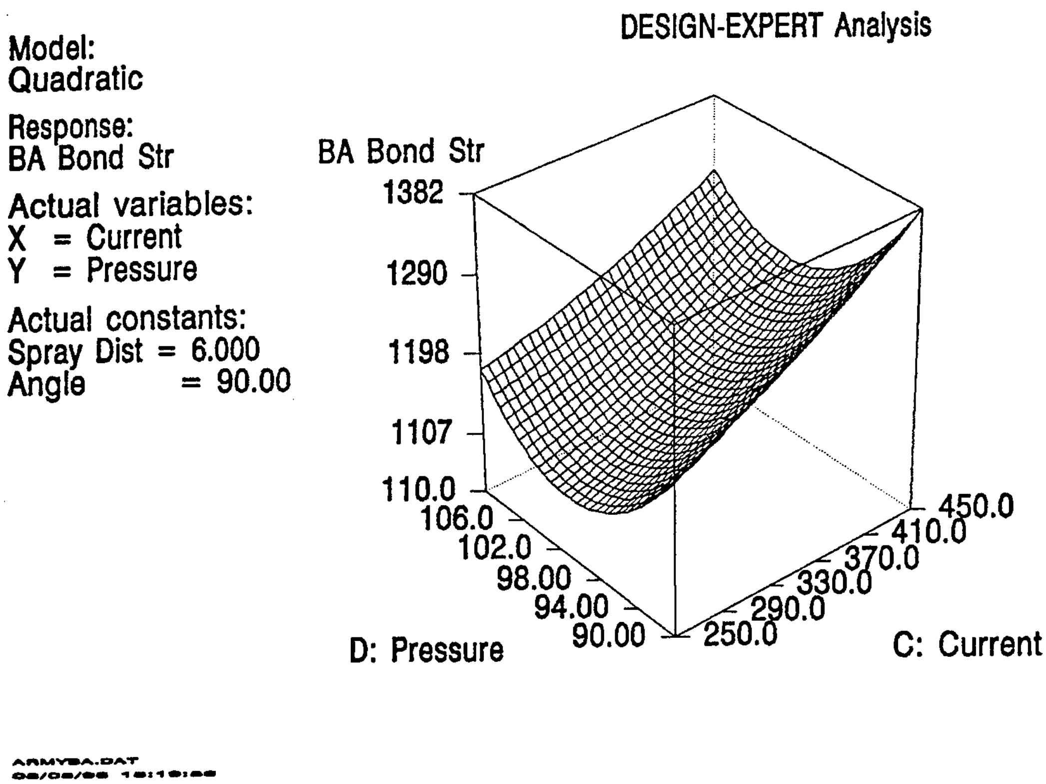

Figure 23. Response Surface Plot of Bond Strength for 3/16" Aluminum

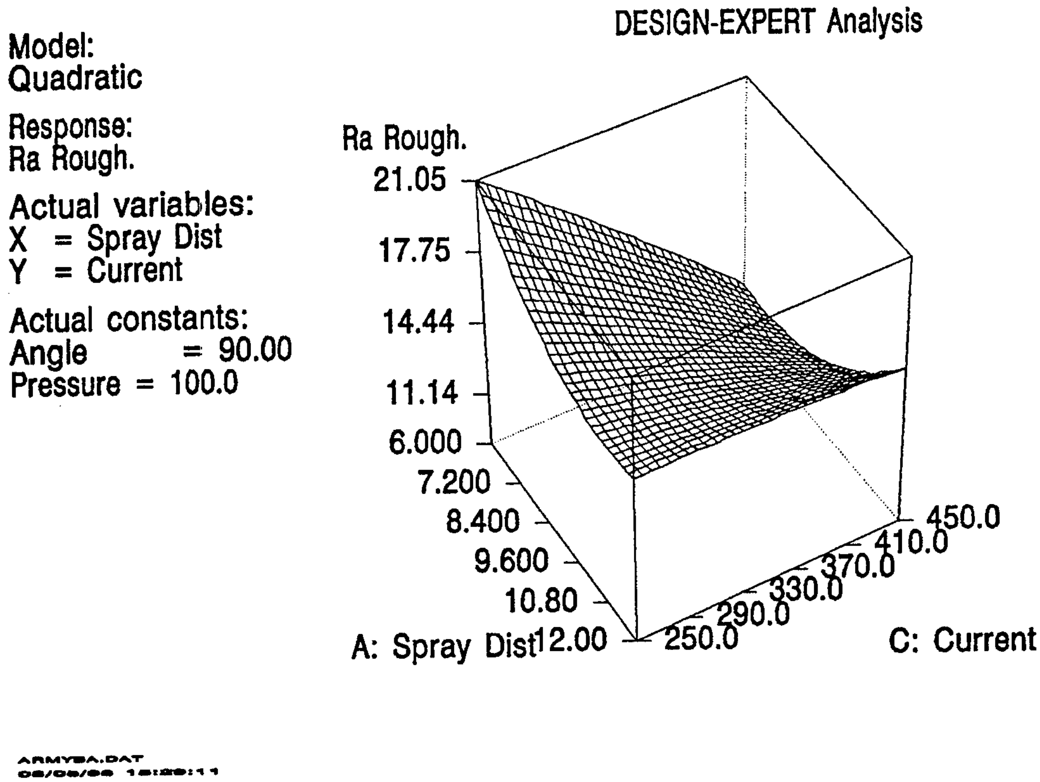

Figure 24. Response Surface Plot of Roughness for 3/16" Aluminum

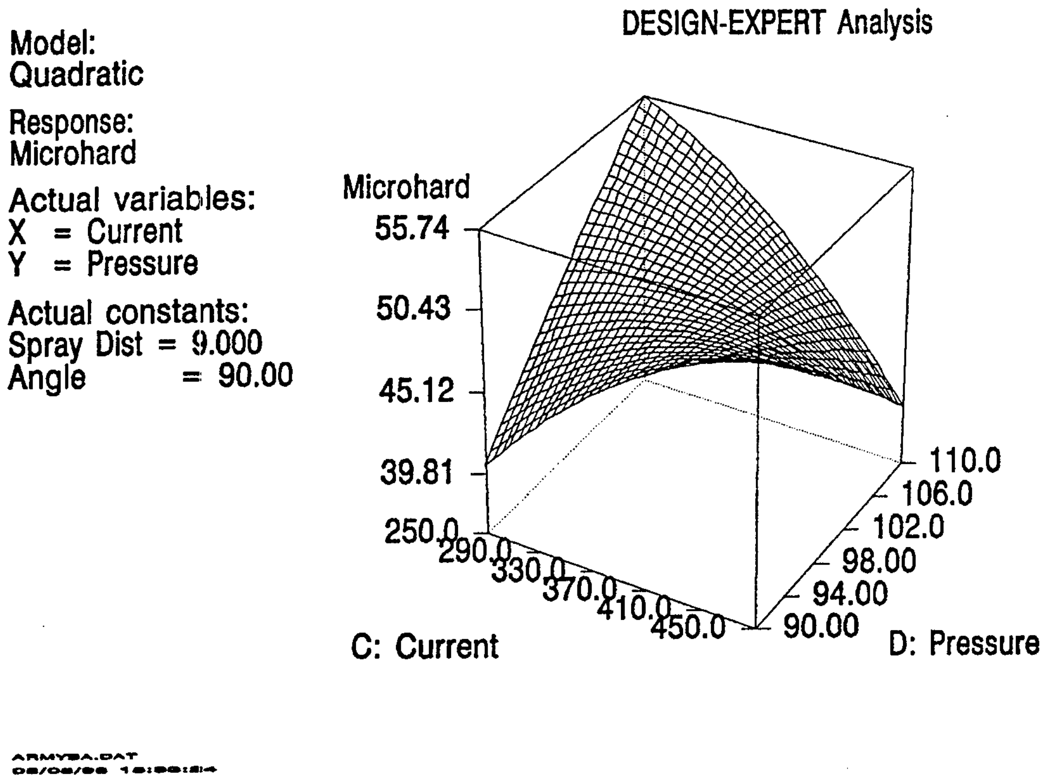

Figure 25. Response Surface Plot of Microhardness for 3/16" Aluminum

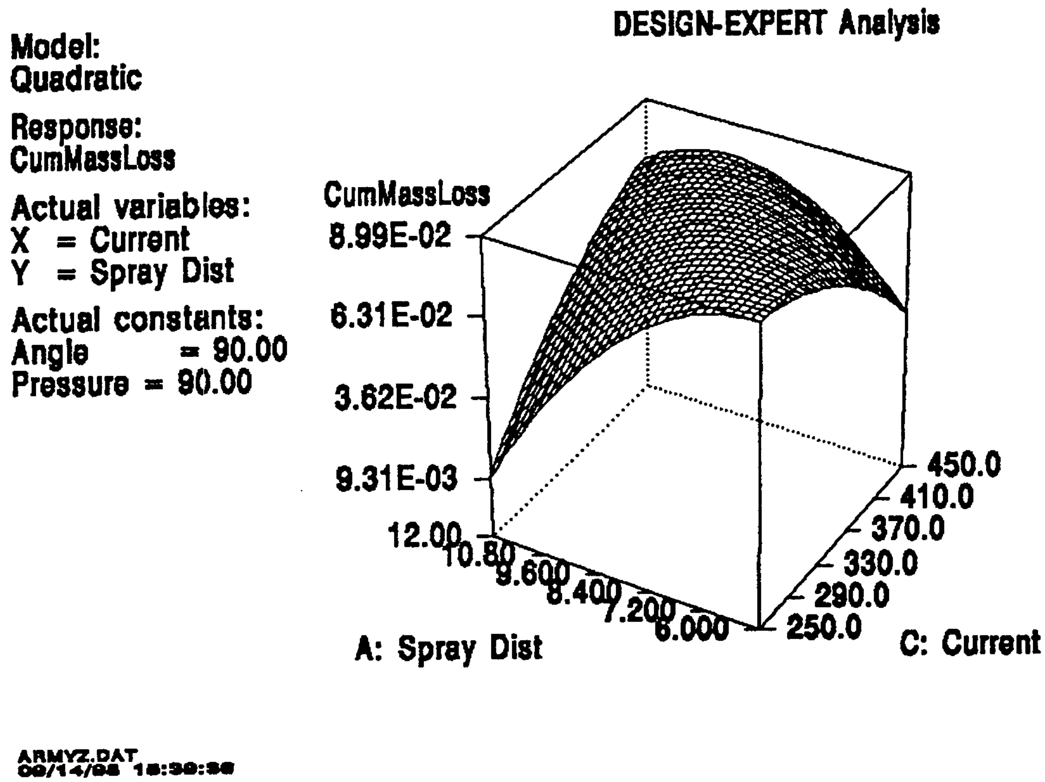

Figure 26. Response Surface Plot of CML for 1/8" Zinc

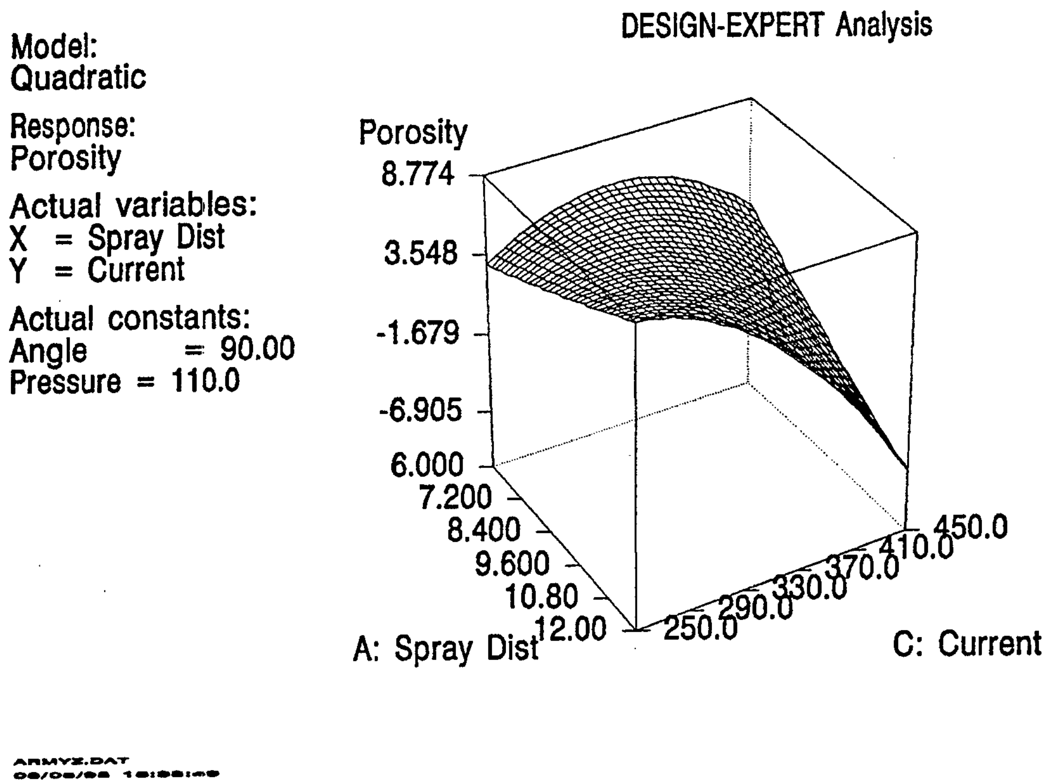

Figure 27. Response Surface Plot of Porosity for 1/8" Zinc

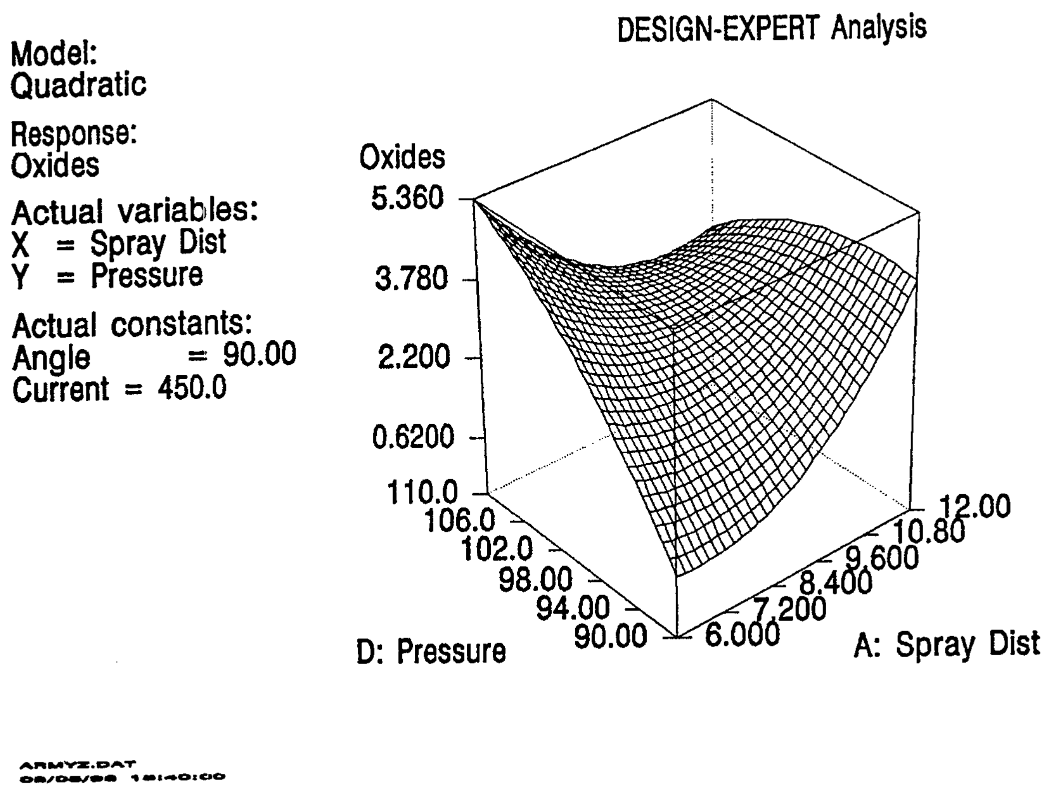

Figure 28. Response Surface Plot of Oxide Content for 1/8" Zinc

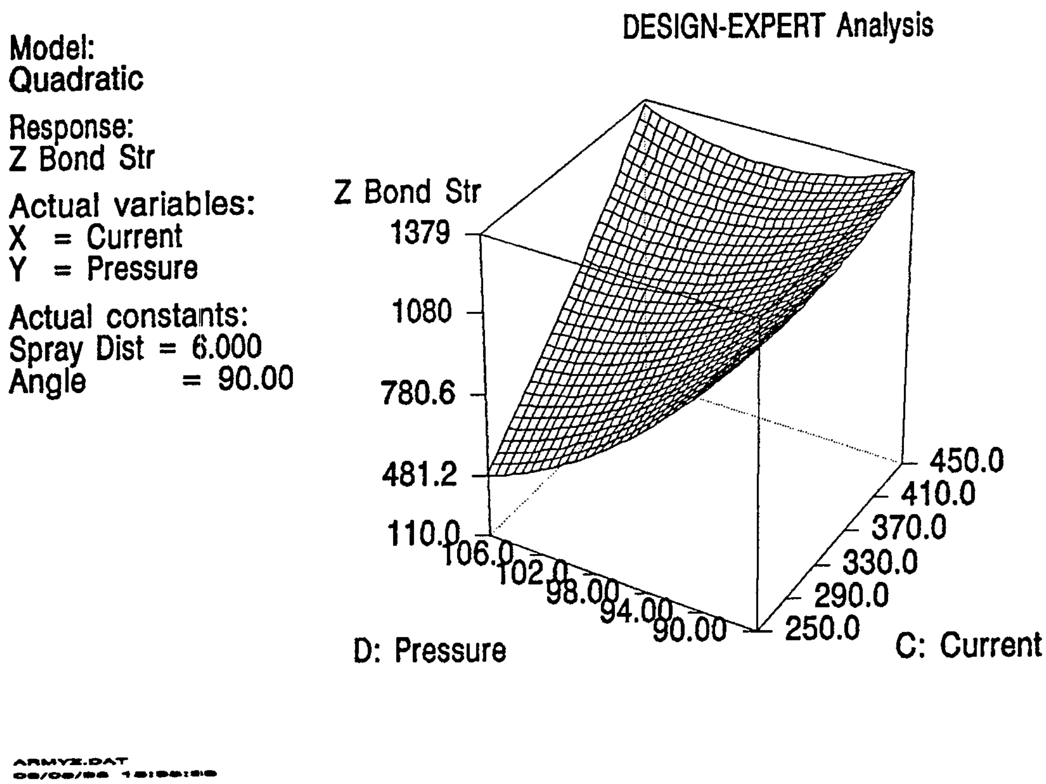

Figure 29. Response Surface Plot of Bond Strength for 1/8" Zinc

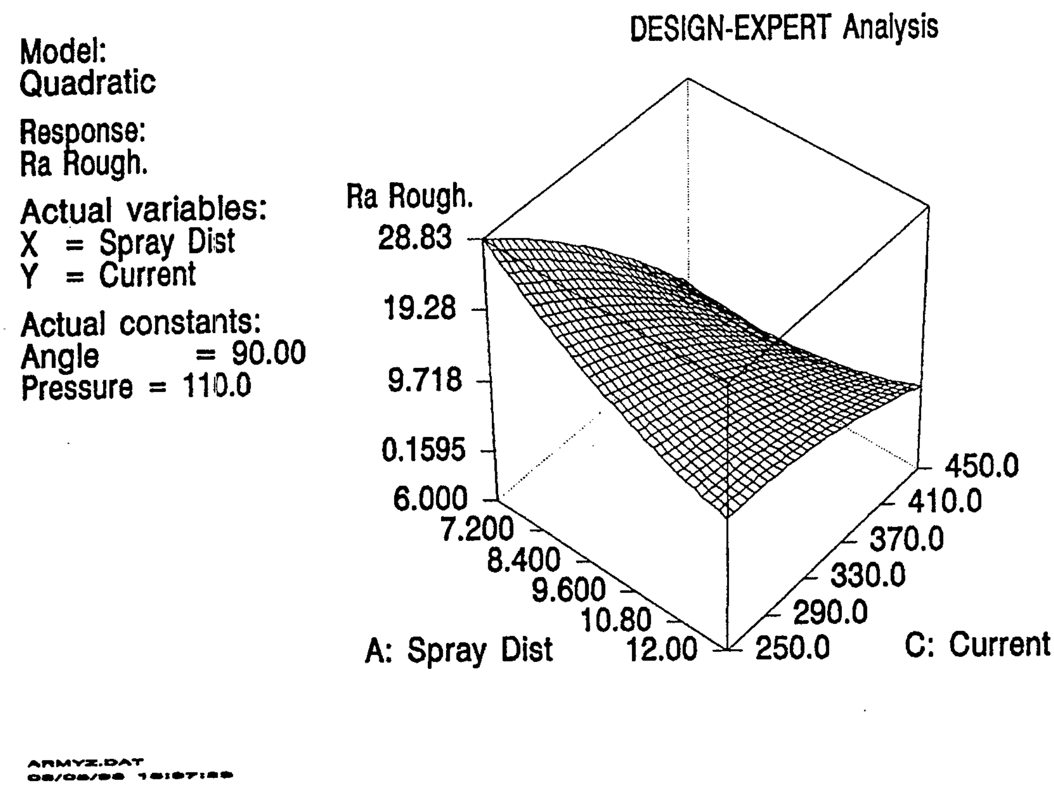

Figure 30. Response Surface Plot of Roughness for 1/8" Zinc

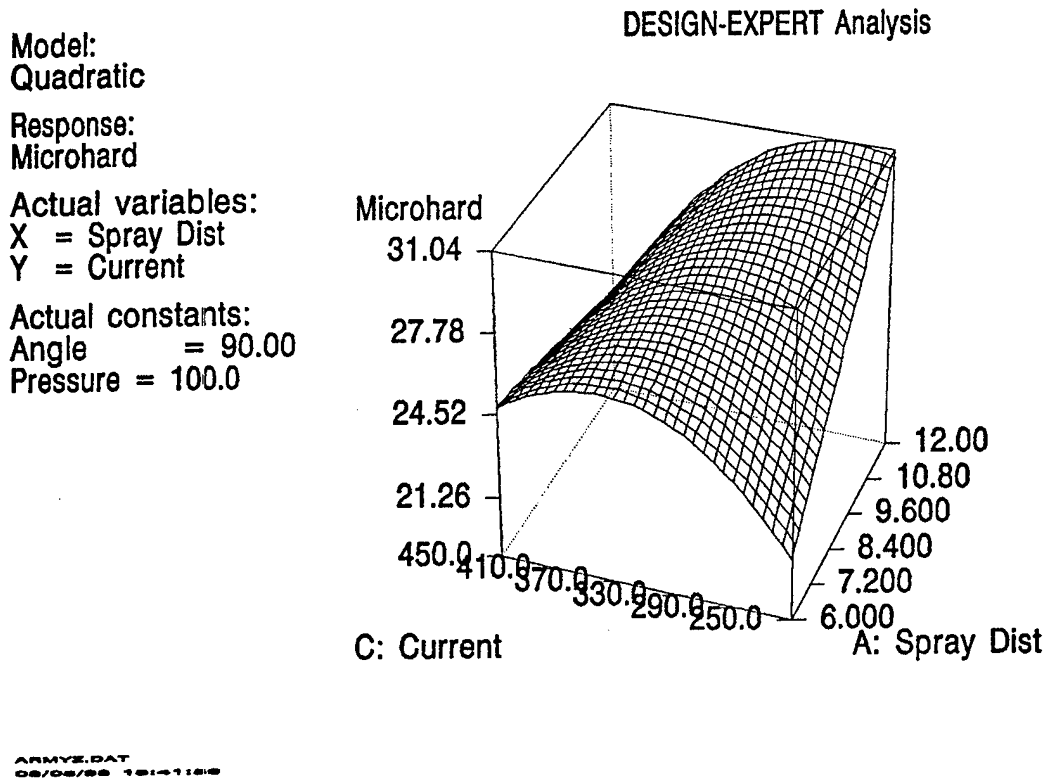

Figure 31. Response Surface Plot of Microhardness for 1/8" Zinc

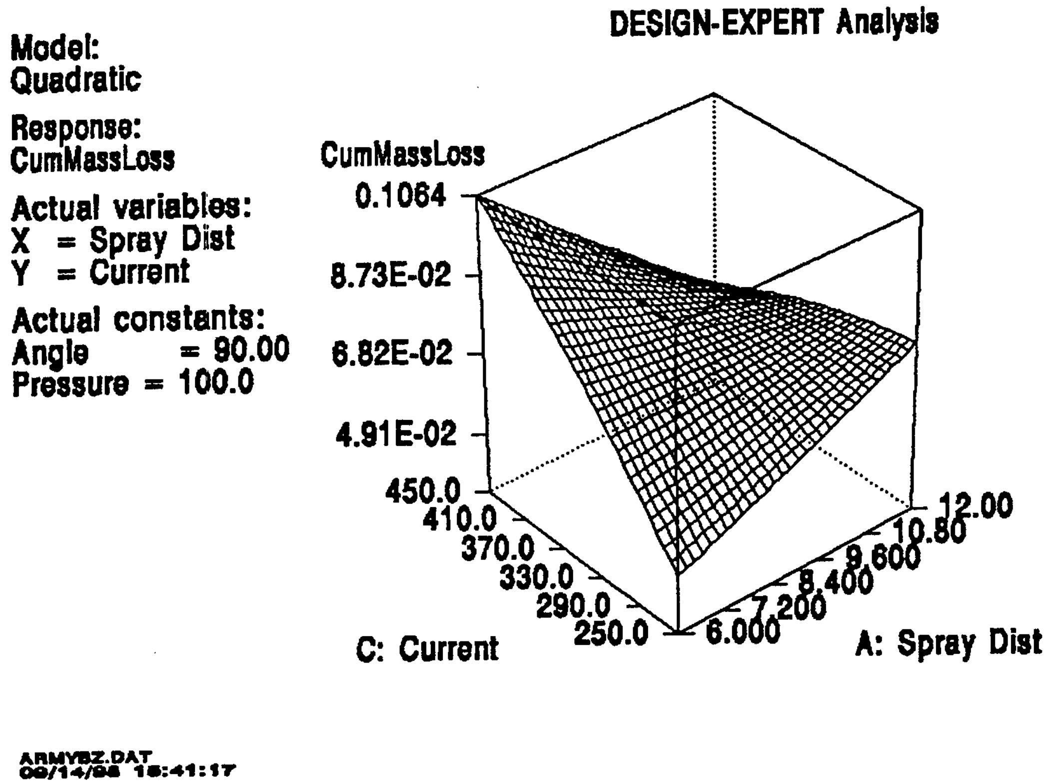

Figure 32. Response Surface Plot of CML for 3/16" Zinc

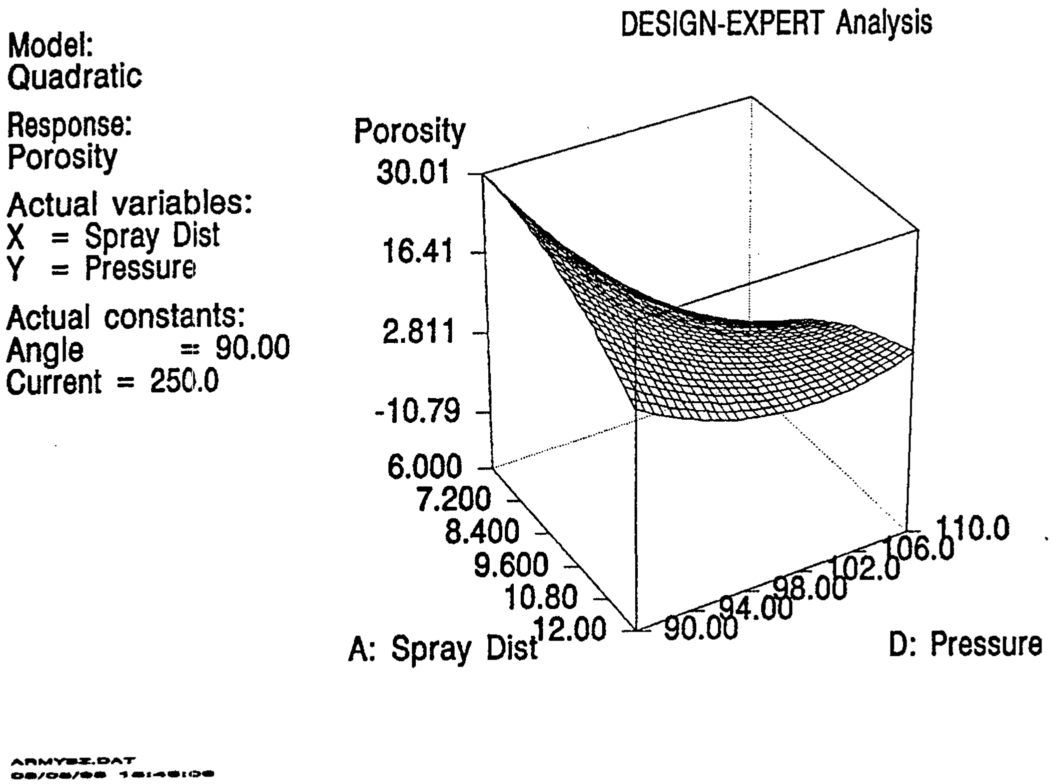

Figure 33. Response Surface Plot of Porosity for 3/16" Zinc

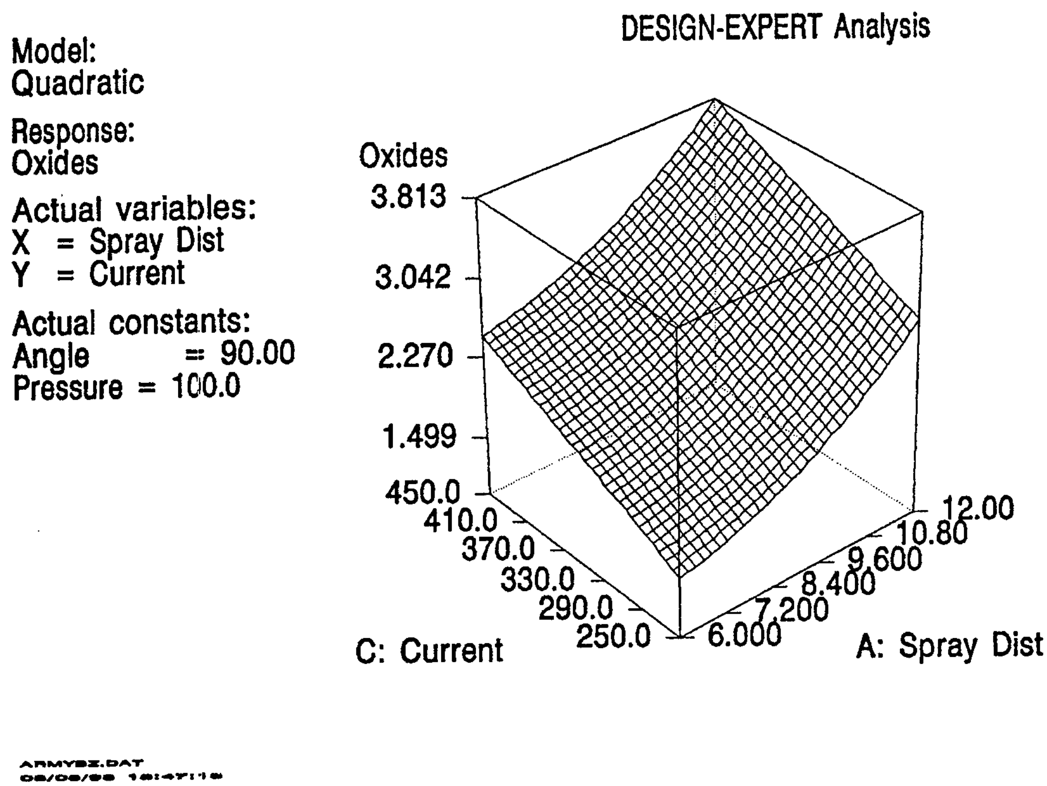

Figure 34. Response Surface Plot of Oxide Content for 3/16" Zinc

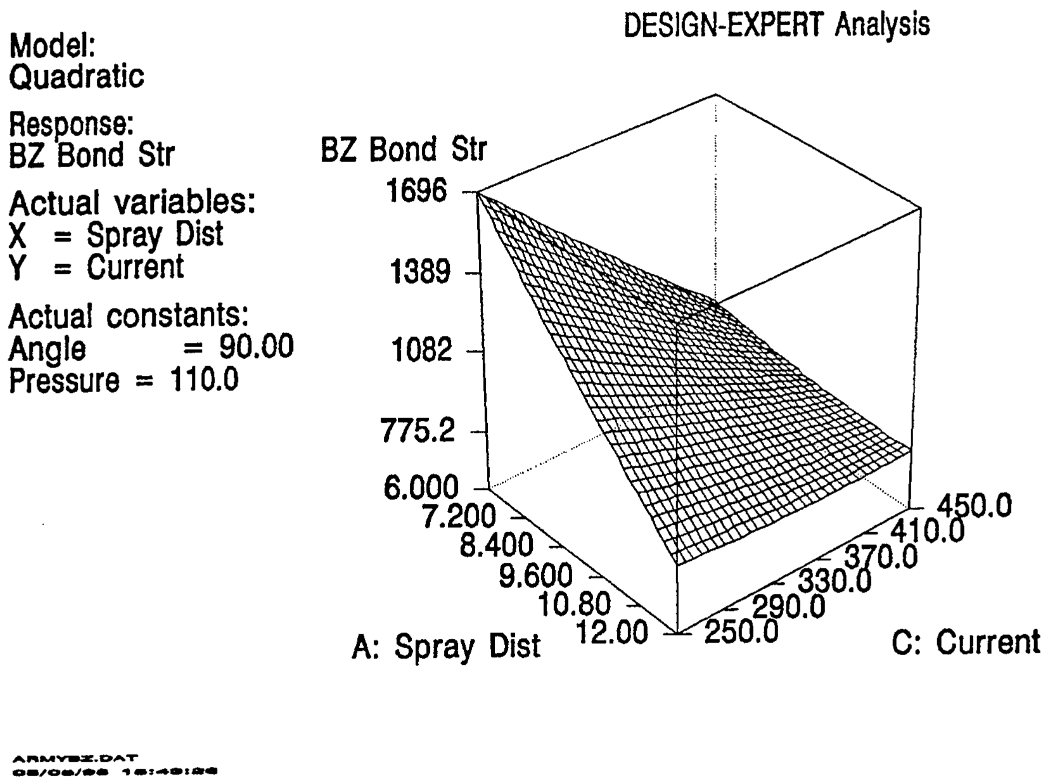

Figure 35. Response Surface Plot of Bond Strength for 3/16" Zinc

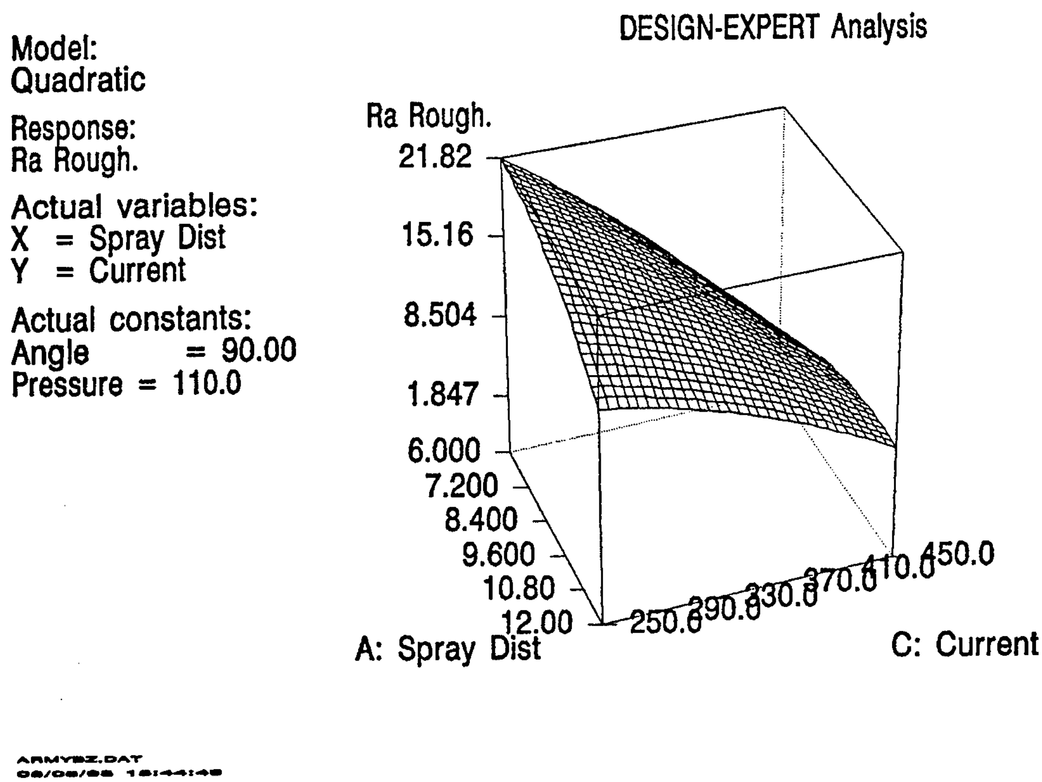

Figure 36. Response Surface Plot of Roughness for 3/16" Zinc

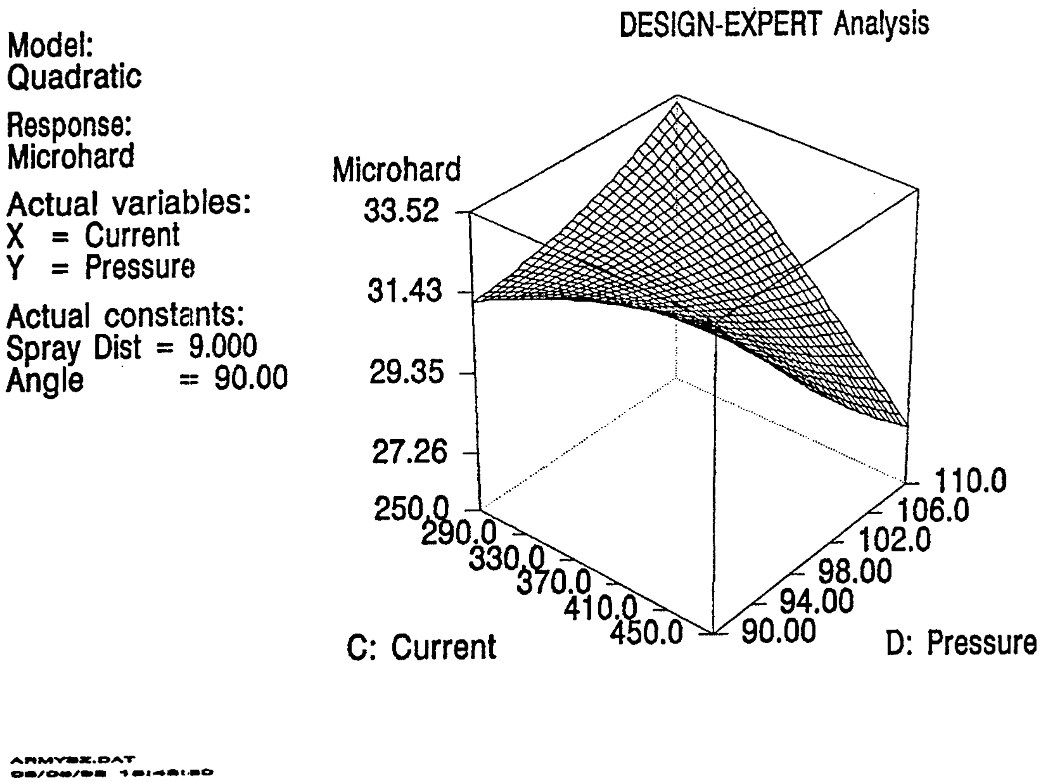

Figure 37. Response Surface Plot of Microhardness for 3/16" Zinc

each attribute as derived from Tables 7 through 12. The figures illustrate the three-dimensional representation of the the data indicated in the tables.

8.3 Process Parameter Optimization Analysis

Analysis was then conducted to determine the optimum parameters for the coating designs. This methodology involved numerical optimization to search for a combination of parameter levels that simultaneously satisfies the requirements placed on each of the responses. The assumptions used for the numerical optimization involved priority weighting only on the attributes of low CML, low porosity, and high bond strength.

The numerical optimization for 1/8" 85/15 is illustrated in Table 13. The optimized process parameters are: spray distance of 8.4", a 90^{o} spray angle, a current of 324 amperes, and a pressure of 110 psia. Predicted coating attributes are shown in the table.

Table 13. Numerical Optimization Results for 1/8" 85/15

FACTOR	MIN	MAX	START	FINISH
Spray Dist	6.000	12.00	9.050	8.433
Angle	85.00	90.00	89.43	87.51
Current	250.0	450.0	406.8	324.3
Pressure	90.00	110.0	101.6	110.0

	OBSERVED		OPTIMIZATION PARAMETERS			WEIGHTS		
RESPONSE	MIN	MAX	GOAL	LOW	HIGH	1ST	2ND	RESULT
E Bond Str	734.0	1427	1400	1000	1427	1.00	1.00	1400
Ra Rough.	9.010	18.71						11.80
Porosity	1.400	11.50	3	1.4	5	2.00	1.00	2.604
Oxides	1.300	4.300						2.734
Microhard	36.70	52.10						42.18
CML	2.38E-02	3.82E-02	0.025	0.0238	0.03	3.00	1.00	2.90E-02

The numerical optimization for 3/16" 85/15 is illustrated in Table 14. The optimized process parameters are: spray distance of 7.7", 90^{o} spray angle, current of 250 amperes, and pressure of 108 psia. Predicted

coating attributes are shown in the table.

Table 14. Numerical Optimization Results for 3/16" 85/15

FACTOR	MIN	MAX	START	FINISH
Spray Dist	6.000	12.00	9.024	7.677
Angle	85.00	90.00	89.02	85.00
Current	250.0	450.0	314.5	250.0
Pressure	90.00	110.0	104.6	108.4

	OBSERVED		OPTIMIZATION	PARAMETERS		WEIGHTS		
RESPONSE	MIN	MAX	GOAL	LOW	HIGH	1ST	2ND	RESULT
BE Bond Str	1049	1437	1400	1100	1437	1.00	1.00	1363
Ra Rough.	8.560	26.82						4.029
Porosity	1.400	21.20	3	1.4	5	2.00	1.00	3.000
Oxides	1.600	4.200						0.6022
Microhard	37.10	51.70						57.10
CML	1.26E-02	3.91E-02	0.015	0.013	0.03	3.00	1.00	2.41E-02

The numerical optimization for 1/8" aluminum is illustrated in Table 15. The optimized process parameters are: spray distance of 6", a 90° spray angle, a current of 379 amperes, and a pressure of 90 psia. Predicted coating attributes are shown in the table.

Table 15. Numerical Optimization Results for 1/8" Aluminum

FACTOR	MIN	MAX	START	FINISH
Spray Dist	6.000	12.00	7.086	6.000
Angle	85.00	90.00	89.28	85.69
Current	250.0	450.0	263.9	379.4
Pressure	90.00	110.0	100.4	90.06

	OBSERVED		OPTIMIZATION	PARAMETERS		WEIGHTS		
RESPONSE	MIN	MAX	GOAL	LOW	HIGH	1ST	2ND	RESULT
A Bond Str	1417	2161	1800	1700	2161	1.00	1.00	1902
Ra Rough.	14.70	27.86						18.26
Porosity	3.100	21.40	5	3.1	7	2.00	1.00	5.000
Oxides	1.000	6.000						9.619
Microhard	47.20	52.40						50.72
CML	2.45E-02	7.09E-02	0.030	0.0245	0.050	3.00	1.00	3.00E-02

The numerical optimization for 3/16" aluminum is illustrated in Table 16. The optimized process parameters are: spray distance of 12", a 90^{o} spray angle, a current of 450 amperes, and a pressure of 100 psia. Predicted coating attributes are shown in the table.

Table 16. Numerical Optimization Results for 3/16" Aluminum

FACTOR	MIN	MAX	START	FINISH
Spray Dist	6.000	12.00	10.57	11.98
Angle	85.00	90.00	86.29	85.00
Current	250.0	450.0	391.9	450.0
Pressure	90.00	110.0	95.28	99.8

	OBSERVED		OPTIMIZATION	PARAMETERS		WEIGHTS		
RESPONSE	MIN	MAX	GOAL	LOW	HIGH	1ST	2ND	RESULT
A Bond Str	784	1356	1100	784	1356	1.00	1.00	1138
Ra Rough.	12.16	26.44						16.64
Porosity	1.300	18.30	4	1.3	7	2.00	1.00	6.348
Oxides	0.7000	9.400						10.61
Microhard	44.00	53.00						50.78
CML	1.32E-02	8.06E-02	0.03	0.0132	0.07	3.00	1.00	6.81E-02

The numerical optimization for 1/8" zinc is illustrated in Table 17. The optimized process parameters are: spray distance of 8", a 90^{o} spray angle, a current of 445 amperes, and a pressure of 103 psia. Predicted coating attributes are shown in the table.

Table 17. Numerical Optimization Results for 1/8" Zinc

FACTOR	MIN	MAX	START	FINISH
Spray Dist	6.000	12.00	8.231	8.097
Angle	85.00	90.00	87.85	89.04
Current	250.0	450.0	429.6	444.8
Pressure	90.00	110.0	108.1	103.3

Table 17. Numerical Optimization Results for 1/8" Zinc (continued)

	OBSERVED		OPTIMIZATION PARAMETERS			WEIGHTS		
RESPONSE	MIN	MAX	GOAL	LOW	HIGH	1ST	2ND	RESULT
Z Bond Str	713	1223	1200	900	1223	1.00	1.00	1200
Ra Rough.	8.91	18.74						4.99
Porosity	1.200	16.80	3	1.2	7	2.00	1.00	3.000
Oxides	1.400	7.900						3.216
Microhard	22.40	33.10						24.59
CML	4.49E-02	0.1448	0.05	0.0449	0.06	3.00	1.00	5.00E-02

The numerical optimization for 3/16" zinc is illustrated in Table 18. The optimized process parameters are: spray distance of 12", a 90^{o} spray angle, a current of 450 amperes, and a pressure of 100 psia. Predicted coating attributes are shown in the table.

Table 18. Numerical Optimization Results for 3/16" Zinc

FACTOR	MIN	MAX	START	FINISH
Spray Dist	6.000	12.00	9.710	12.00
Angle	85.00	90.00	87.48	90.00
Current	250.0	450.0	419.0	450.0
Pressure	90.00	110.0	99.5	100.3

	OBSERVED		OPTIMIZATION PARAMETERS			WEIGHTS		
RESPONSE	MIN	MAX	GOAL	LOW	HIGH	1ST	2ND	RESULT
BZ Bond Str	683	1019	950	750	1019	1.00	1.00	896.7
Ra Rough.	11.12	22.18						12.62
Porosity	5.300	19.70	7	5.3	9	2.00	1.00	7.000
Oxides	0.5000	5.900						3.794
Microhard	25.40	34.60						27.54
CML	4.94E-02	0.1018	0.050	0.0494	0.070	3.00	1.00	6.00E-02

For all six cases, the derived predicted properties are better than the optimum coatings of this study discussed in the characterization section. Confirmation runs should be conducted in order to confirm these optimized parameters.

The statistical methodology employed in this study is significant in

that it finalizes coating design studies by optimizing the most important process or coating attributes and the process parameters that affect these attributes. The attributes may differ for the same material in different applications, and the baseline data generated in this study can be used to develop specific confirmation runs that approach other desired application attributes.

At this juncture, a quadratic process parameter/coating attribute relationship was established. Multiple regression analysis was then required to develop the relationship between the coating attributes and the coating performance (i.e. abrasion resistance). In this manner the complete parameter/property/performance relationship was defined.

8.4 Regression Analysis

Sequential regression analysis was then utilized to establish a relationship between the process parameters, the coating microstructural attributes, and the coating corrosion performance.

The quadratic regression analysis from the characterization ANOVA analysis established the relationship between the process parameters (i.e. orifice diameter, gun pressure, current, and spray distance), and the coating attributes (i.e. CML, bond strength, porosity, oxide content, roughness, hardness).

The Minitab[5] code was then used to establish the relationship between the coating attributes, and the dependent variable of cumulative mass loss for the six material systems. Tables A7, B7, C7, D7, E7, and F7 illustrate the Minitab analysis conducted for the six systems. In all cases the error of the regression equations is low and the residuals from the equations are low indicating the validity of the analyses.

Equation 2 illustrates a typical equation derived from the regression analysis that illustrates the property/performance relationship for the 1/8" 85/15 system. The equations are listed in the respective appendix. The equations signify the erosion resistance for the experiments of this study as a function of the coating attributes of roughness (R), porosity

(P), oxide content (O), bond strength (BS), and microhardness (MH). The lowest value of CML would be the most erosion resistant coating.

The regression equation for the 1/8" 85/15 system is:

$$CML = 0.505 - 0.00324\ P - 0.0261\ O - 0.0181\ MH - 0.000000\ BS2 + 0.000077\ R2 + 0.000140\ P2 + 0.00385\ O2 + 0.000196\ MH2 - 21.5\ 1/BS + 0.386\ 1/R - 0.0055\ 1/O - 0.0697\ 1/P2 \qquad \text{Equation 2}$$

Figures 38 through 43 illustrate the predicted erosion resistance as a function of the coating attributes for the six material systems. In these plots the characterization variables of oxide content, microhardness, and bond strength are held at the average values shown in Tables 4a thorugh 4f for use in the regression equations.

Figure 38 illustrates the erosion resistance as a function of the porosity and roughness for the 1/8" 85/15 system. As shown, the erosion resistance increases (i.e. low CML) with decreasing porosity. Roughness does not have any significant effect. CML is at a minimum at the lowest porosity and intermediate roughness.

Figure 39 illustrates the erosion resistance as a function of the porosity and roughness for the 3/16" 85/15 system. As shown, the erosion resistance also increases (i.e. low CML) with decreasing porosity and roughness. CML is at a minimum at the lowest porosity and roughness.

Figure 40 illustrates the erosion resistance as a function of the porosity and roughness for the 1/8" aluminum system. As shown, the erosion resistance increases (i.e. low CML) with decreasing porosity and roughness. CML is at a minimum at the lowest porosity and roughness.

Figure 41 illustrates the erosion resistance as a function of the porosity and roughness for the 3/16" aluminum system. As shown, the erosion resistance follows the trends of the 1/8" system, also increasing (i.e. lower CML) with decreasing porosity. Roughness has little effect on the CML. The CML is at a minimum at the lowest porosity and roughness.

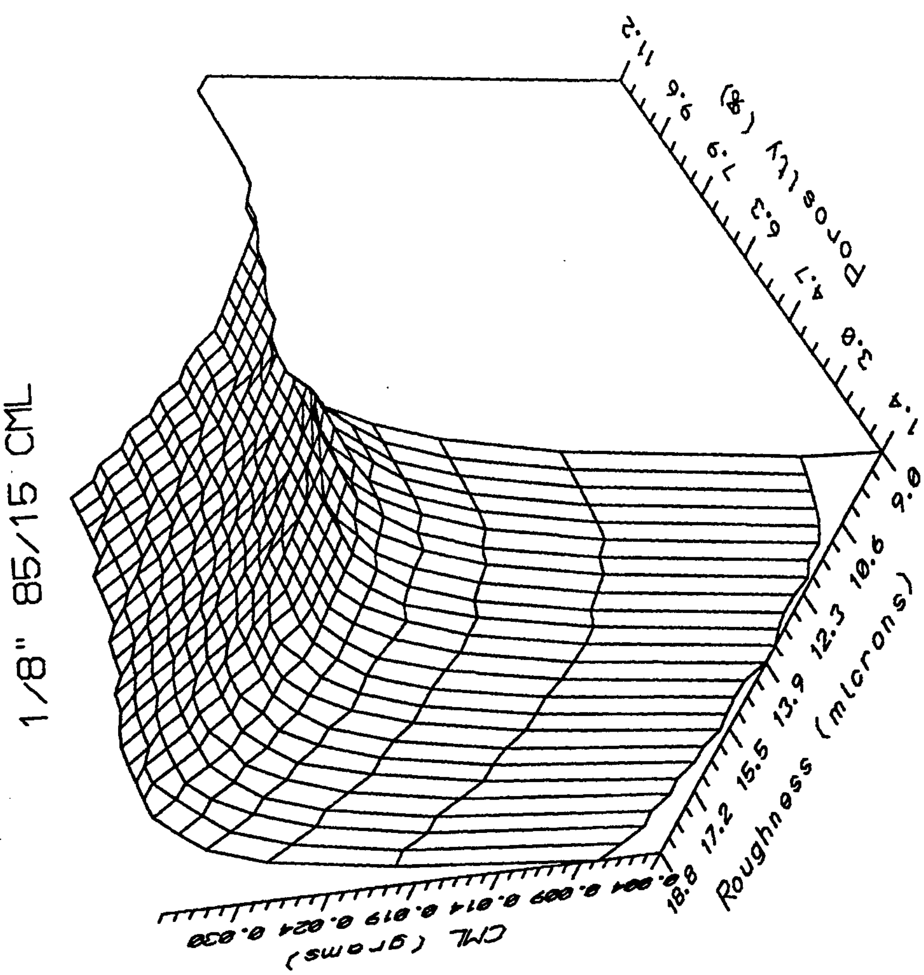

Figure 38. Predicted Erosion Resistance for 1/8" 85/15

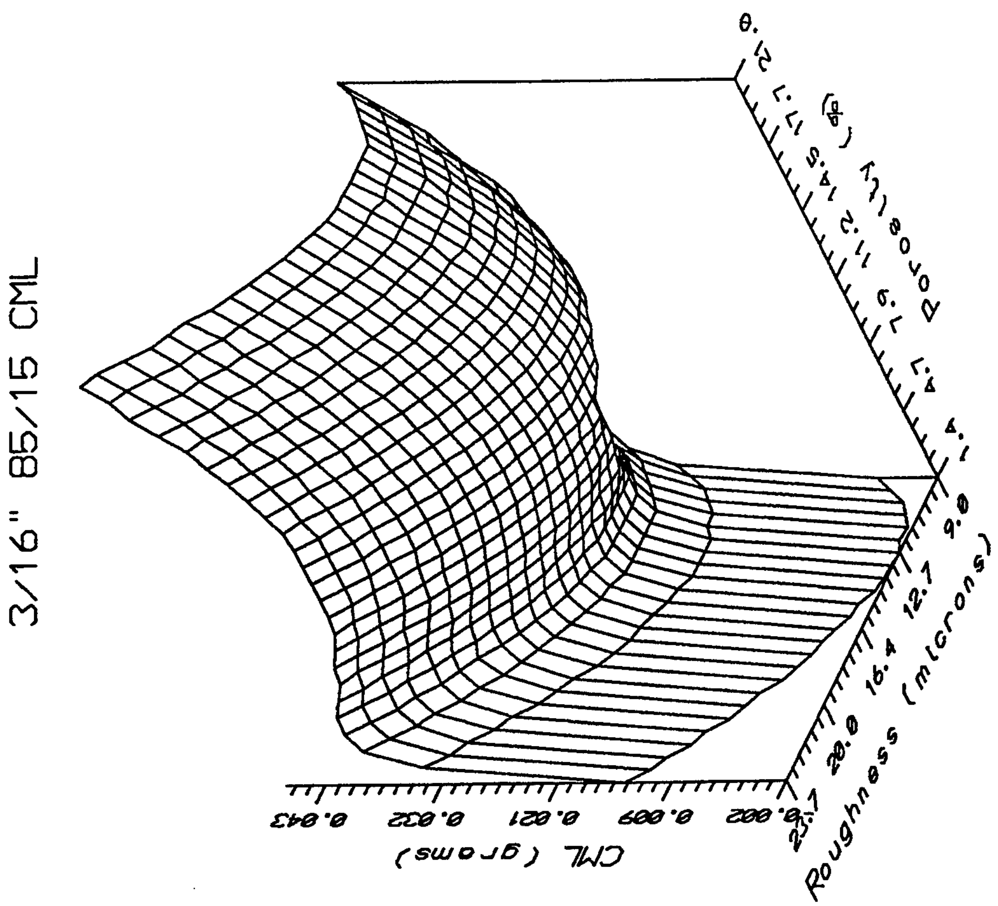

Figure 39. Predicted Erosion Resistance for 3/16" 85/15

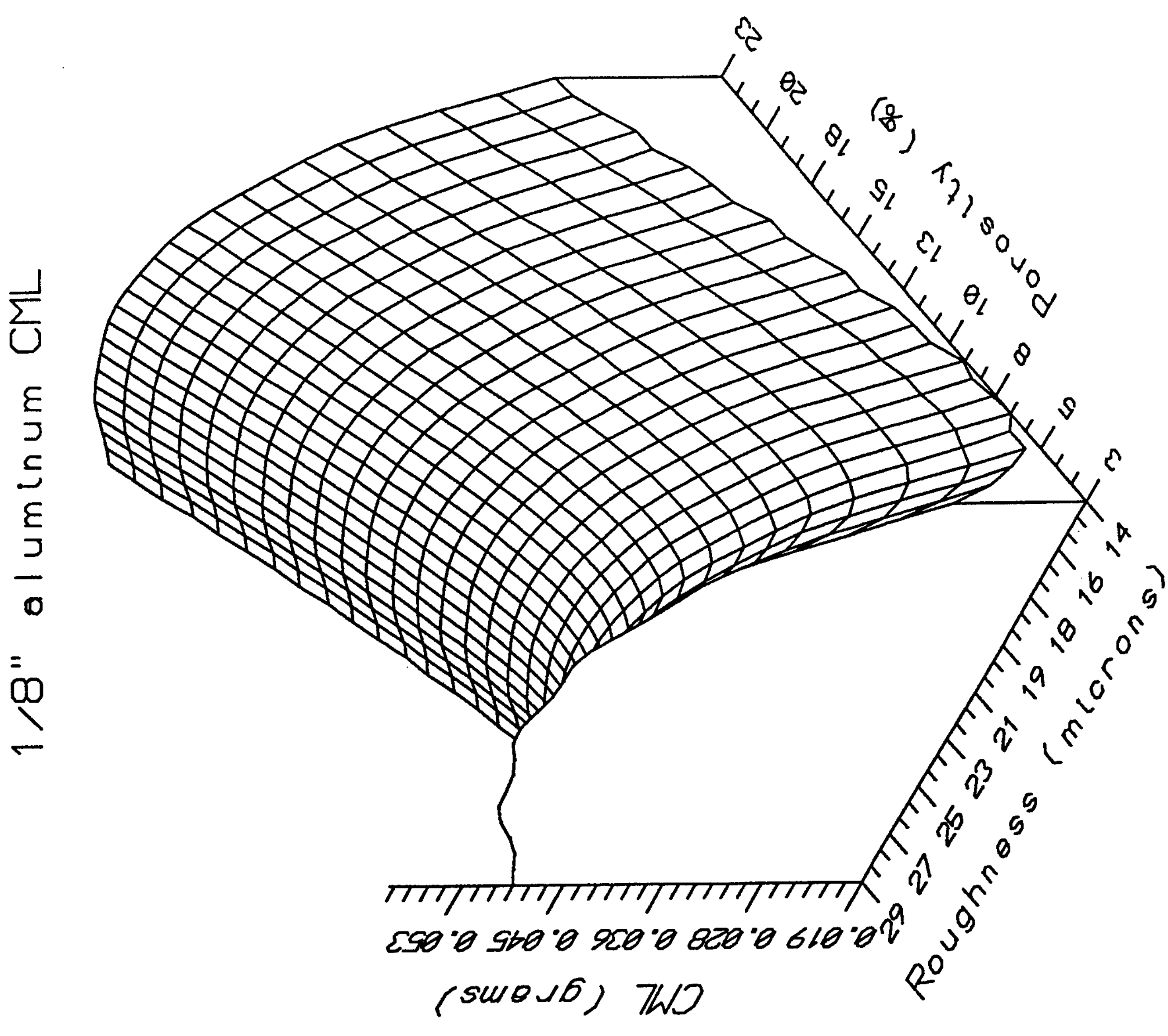

Figure 40. Predicted Erosion Resistance for 1/8" Aluminum

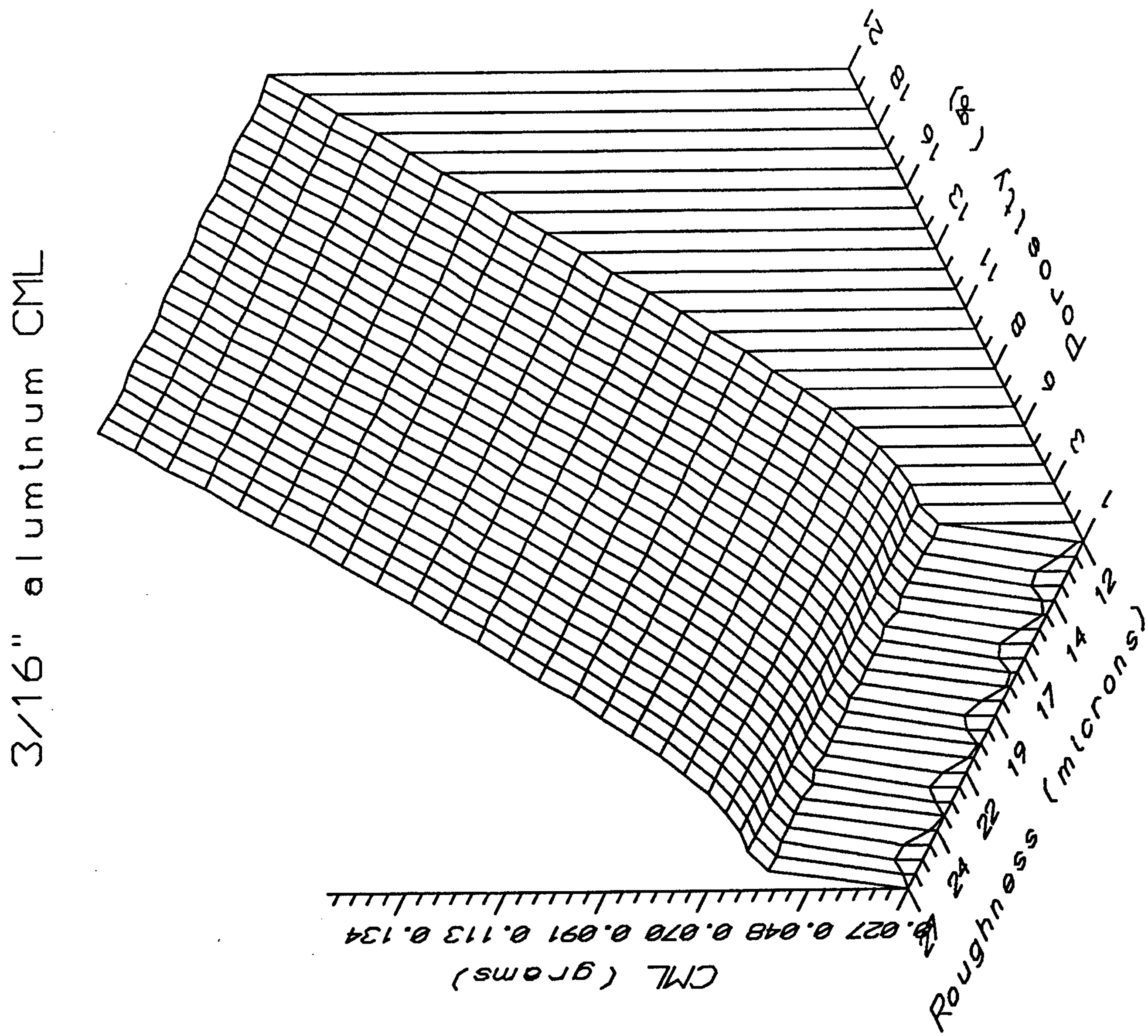

Figure 41. Predicted Erosion Resistance for 3/16" Aluminum

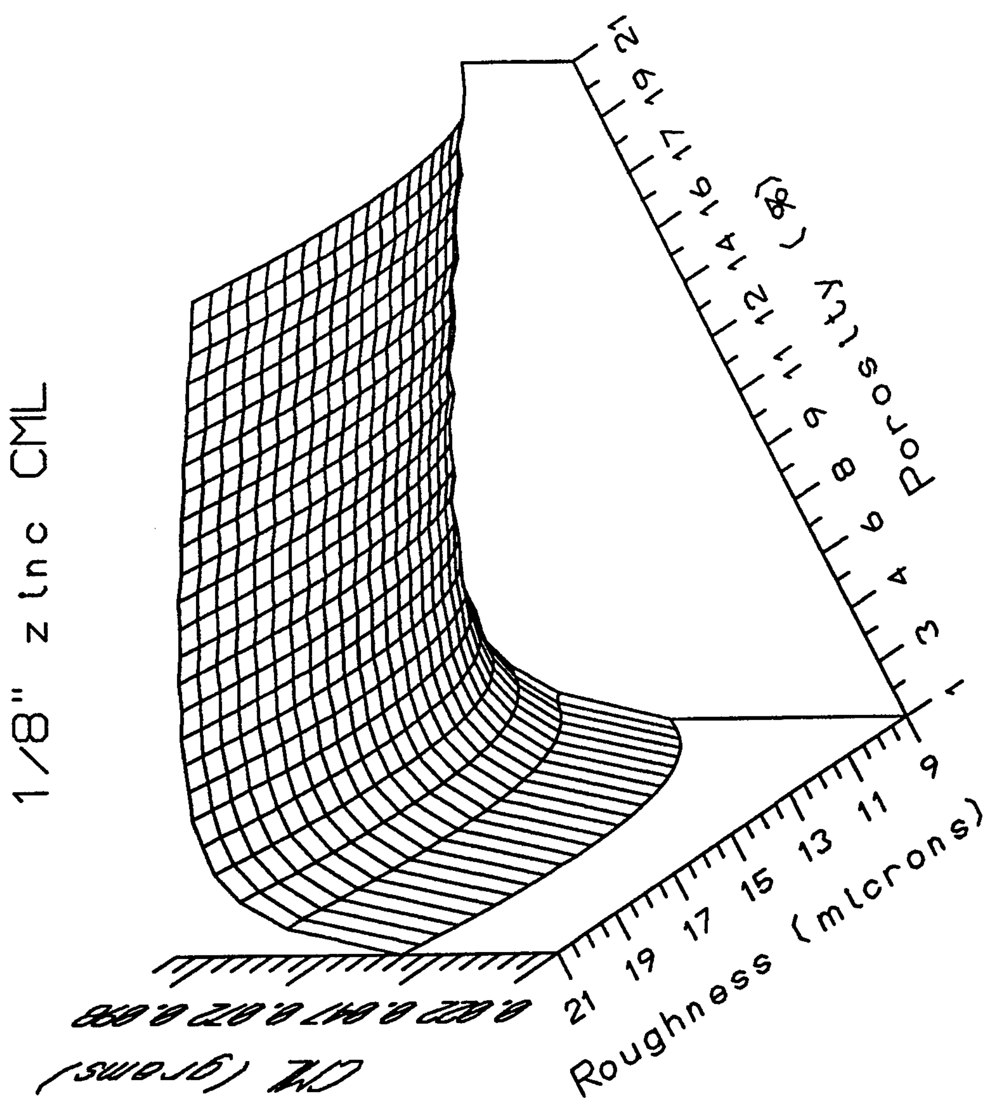

Figure 42. Predicted Erosion Resistance for 1/8" Zinc

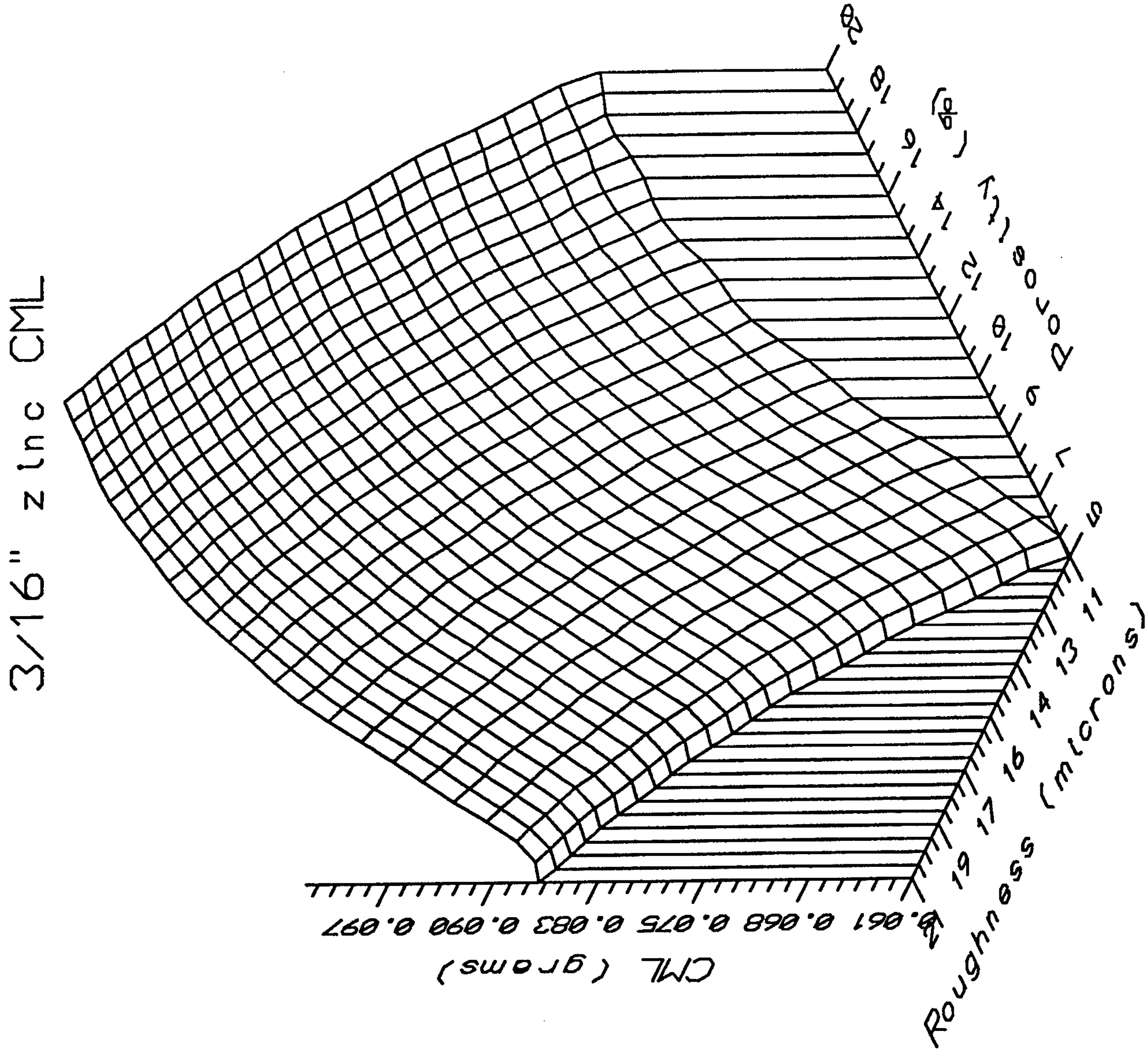

Figure 43. Predicted Erosion Resistance for 3/16" Zinc

Figure 42 illustrates the erosion resistance as a function of the porosity and roughness for the 1/8" zinc system. As shown, the erosion resistance increases (i.e. low CML) with decreasing porosity. Roughness has little effect on the CML. The CML is at a minimum at the lowest porosity and intermediate roughness.

Figure 43 illustrates the erosion resistance as a function of the porosity and roughness for the 3/16" zinc system. As shown, the erosion resistance increases (i.e. lower CML) with lower porosity and roughness. The CML is at a minimum at the lowest porosity and roughness.

By substitution of the characterization equations into the regression equations, the complete parameter/property/performance relationship is established for each material system.

9.0 Recommendations for Use of the TWEA Process in the Field

9.1 Substrate preparation

Substrate surface preparation prior to thermal spraying is absolutely essential. Steps must be executed correctly for the coating to perform to design expectations. At worst, total failure could occur.

Recommendations:

1. Clean the surface to be sprayed. Remove contaminants such as oil, grease, paint, rust, scale and moisture. Contaminants will reduce bond strength.
2. Manual cleaning with solvents is often all that is necessary to remove surface grease and oils.
3. The single most critical step to ensure coating adhesion is grit blasting. Dry abrasive grit blasting is the more commonly used roughening technique. A properly prepared surface has a white sheen to the metal. Best results use a 3 mil sawtooth profile for the grit blasted surface, as illustrated in the bond strength experiments of this study. In general, for both the 1/8" and 3/16" wire of this study, the 3 mil profile exhibited higher bond strengths than the 1 mil profile.

9.2 Equipment:

1. Wire feed in a TWEA is strictly mechanical. The wire tips need to be continually and uniformly fed into the heating zone for melting in the arc. Position of the wire and feed rate are extremely important in controlling the coating porosity, surface texture, bond and thickness.

Recommendations:

1. Less than 5 m (16 ft.) is recommended between the drive wheel and the wire feed source.
2. Avoid kinks in the wires. If wires kink and become bent, the feeding of the wire will affect feed uniformity.
3. Gradual changes in wire feed contour must be observed. Larger, stiffer wires, become more difficult to feed as uncoiling takes more force and leads to larger wire tension variations.

2. Atomizing air is used to cool the electrode contact area and atomize the melting wire tips. As shown in the effects analysis in Tables 7 through 12, pressure has a substantial effect on many of the coating attributes and should be monitored closely once the job parameters have been selected.

Recommendations:

1. Dry, contaminate- and oil-free, high-flow air is essential. Oil and moisture in the air will contribute to coating oxidation, substrate contamination, and coating inclusions.
2. Atomizing air flow and nozzle jet configuration play a strong role in droplet size and distribution as well as in determining the spray pattern (size and shape) of a wire-arc spray system.
3. In general, higher flow yields higher particle speed, which shortens a particle's residence time and creates a finer droplet distribution, leading to denser and lower oxide coatings.

9.3 Coating application

The fundamental objective for gun and substrate motion during spraying is to present the target area to the spray stream in a steady, consistent

and repeatable manner always maintaining the same gun-to-substrate spray angle, stand off (spray distance) and relative motion.

1. Gun angle: thermal spraying is a line-of-sight-process. Complex shapes or contours require special attention. Deviation from normal (perpendicular) spray will often compromise coating properties. Porosity may increase and coating integrity will decrease. As shown in the effects analysis in Tables 7 through 12, gun angle drastically affects all coating parameters.

Recommendations:

1. Study the component/part shape and identify the area where the coating is to be applied. The stream of spray particles should impact the target surface at close to normal (90^{o}) as possible. The minimum acceptable impingement angle is 45^{o} to the target area. Use high spray angles only as a last resort. As shown in Tables 4a through 4f, spraying at drastic angles compromises the coating properties, and does not yield an optimum coating.
2. Porosity increases dramatically as the spray gun is moved from 90^{o} to 67.5 to 45^{o}. Spray a sample coating at the impingement angle required and test its integrity before committing to spray the high spray angle.

2. Spray distance: spray distance control ensures the same coating is deposited across the entire target area and throughout the total thickness.

Recommendations:

1. Once spray distance is established it must be kept constant for the entire operation regardless of part or gun movement. This study proved that porosity can vary 15%, and bond strength can vary 700 psia for spray distances from 6 to 12 inches.

3. Feedrate: feedstock consumption establishes the rate of coating deposited as the spray stream passes over the target.

Recommendations:

1. Do not change spray rate while spraying. This leads to uneven coating thickness, and coating properties can vary from those intended.
2. An even and consistent coating thickness should be applied after each layer. As a general rule, 50 microns (0.002 in.) of coating thickness should be applied per TWEA layer; therefore, a 250-micron (0.010-in.) thick coating requires 5 layers. Layer thickness chosen can change and often does to accommodate the application.

4. Spray motion and speed: to determine the speed of gun motion relative to the sprayed item, each pass of the gun over the surface should deposit an even band of deposited coating.

Recommendations:

1. Adjust the relative motion of the gun so that the spray pattern is moved approximately one half the spray pattern diameter for each pass over the target area. This overlap will produce a smooth and continuous layer.
2. After the gun is moved in the x direction across the surface, index it in the y direction for the next adjacent pass, and so on to cover the target area. Properly applied the coating will be deposited in equal layers.
3. A comfortable manual traverse rate is 12 in/sec.

10.0 Summary and Conclusions

An experimental study of the twin-wire electric arc spraying of 1/8" and 3/16" 85/15, aluminum, and zinc wire has been presented. Box type, fractional-factorial design of experiments were conducted. Major parameters investigated in the TWEA statistical studies included spray distance, gun angle, current, and gun pressure. The coating attributes evaluated included porosity, roughness, oxide content, bond strength, microhardness, and corrosion resistance. These studies led to optimized process parameters for this particular application for each material

system. In this study, the coating designs were based on the determination of the most erosion resistant coating. The empirical studies were conducted to determine if zinc and aluminum coatings sprayed with a TWEA spray system could perform as abrasive corrosion resistant coatings for infrastructural and ACERL site-specific applications.

Coatings were characterized and evaluated by a number of techniques for the six material systems:

SDE bond strength experiments: the bond strength ranged from 734 to 1427 psia for the 1/8" 85/15 coatings, 1049 to 1437 psia for the 3/16" 85/15 coatings, 1417 to 2161 psia for the 1/8" aluminum coatings, 784 to 1356 psia for the 3/16" coatings, 713 to 1223 psia for the 1/8" zinc coatings, and 683 to 1019 psia for the 3/16" coatings.

Classical bond strength experiments: for both 1/8" and 3/16" wire, the 3 mil blast profile exhibited higher bond strengths than the 1 mil profile. The aluminum coatings exhibited the highest bond strengths followed by the 85/15 coatings, and then the zinc coatings. The steel grit, copper slag, and alumina grit exhibited comparable bond strengths, while the steel shot exhibited extremely low bond strengths.

Roughness: the average roughness ranged from 9.0 to 18.7 microns for the 1/8" 85/15 coatings, 8.6 to 26.8 microns for the 3/16" 85/15 coatings, 14.7 to 27.9 microns for the 1/8" aluminum coatings, 12.2 to 26.4 microns for the 3/16" aluminum coatings, 8.9 to 18.7 microns for the 1/8" zinc coatings, and 11.1 to 22.2 microns for the 3/16" zinc coatings.

Porosity: the porosities of the 1/8" 85/15 coatings ranged from 1.4 to 11.5%, the 3/16" 85/15 coatings ranged from 1.4 to 21.2%, the 1/8" aluminum coatings ranged from 3.1 to 21.4%, the 3/16" aluminum coatings ranged from 1.3 to 18.3%, the 1/8" zinc coatings ranged from 1.2 to 16.8%, while the porosities of the 3/16" zinc coatings ranged from 5.3 to 19.7%.

Oxide content: the 1/8" 85/15 coatings ranged from 1.3 to 4.3%, the 3/16" 85/15 coatings ranged from 1.6 to 4.2%, the 1/8" aluminum coatings ranged from 1.0 to 6.0%, the 3/16" aluminum coatings ranged from

0.7 to 9.4%, the 1/8" zinc coatings ranged from 1.4 to 7.9%, and the 3/16" zinc coatings ranged from 0.5 to 5.9.

Vickers microhardness: measurements ranged from 36.7 to 52.1 for the 1/8" 85/15 coatings, 37.1 to 51.7 for the 3/16" 85/15 coatings, 47.2 to 52.4 for the 1/8" aluminum coatings, 44 to 53 for the 3/16" aluminum coatings, 22.4 to 33.1 for the 1/8" zinc coatings, and 25.4 to 34.6 for the 3/16" zinc coatings.

Deposition efficiency: deposition efficiency for the 1/8" 85/15 coatings was nominally 64%, while the deposition efficiency for the 3/16" 85/15 coatings was nominally 68%. Deposition efficiency for the 1/8" aluminum coatings was nominally 64%, while the deposition efficiency for the 3/16" aluminum coatings was nominally 74%. Deposition efficiency for the 1/8" zinc coatings was nominally 57%, while the deposition efficiency for the 3/16" zinc coatings was nominally 65%. The 3/16" aluminum and 3/16" zinc systems showed a slight increase in DE with current, while the 3/16" 85/15 system showed a slight decrease. The 1/8" systems did not indicate any substantial effects from current. In all cases, the 3/16" wire exhibited higher DE than the 1/8" wire.

Abrasion Resistance: coupons were measured for cumulative mass loss at 1, 2, and 5 minutes. At five minutes, the CML of the 1/8" 85/15 coatings ranged from 0.024 to 0.038 grams, while the CML of the 3/16" 85/15 coatings ranged from 0.0126 to 0.0391 grams. At five minutes, the CML of the 1/8" aluminum coatings ranged from 0.0245 to 0.0709 grams, while the CML of the 3/16" aluminum coatings ranged from 0.0132 to 0.0806 grams. At five minutes, the CML of the 1/8" zinc coatings ranged from 0.0449 to 0.1448 grams, while the CML of the 3/16" zinc coatings ranged from 0.0494 to 0.1018 grams. The lowest value of CML is the most abrasive resistant coating.

Microstructures: based on the criteria of either low CML or low porosity, the coatings for the six systems vary substantially in quality. No cracking nor unmelted particles were evidenced in the body of any of the coatings.

85/15 coatings: all of the 85/15 photomicrographs indicate very dense coatings with homogenuously dispersed porosity. The splat morphologies are very similar for all of the coatings with a tendency for large diameter, thin lamellar structures.

Aluminum coatings: t photomicrographs indicate very porous coatings (i.e. porosity average is 10%), which is dispersed homogenuously throughout the coating matrices. The splat morphologies are very similar for all of the coatings with a tendency for small diameter, thick lamellar structures.

Zinc coatings: the zinc photomicrographs indicate coatings with intermediate porosity (i.e. porosity averages: Z = 7.6%, BZ = 11.2%). The porosity is dispersed homogenuously throughout the coating matrices. The splat morphologies are very similar to the 85/15 coatings.

Trend analysis based on the coating characterization and performance evaluation results indicated the following:

1. 85/15: higher porosity and roughness evidenced for larger wire; no effect on wire size for hardness, oxide content, CML, and bond strength.

2. Aluminum: lower bond strength and higher oxide content evidenced for larger wire; no effect on wire size for hardness, porosity, CML, and roughness.

3. Zinc: higher porosity, higher roughness, and lower CML evidenced for larger wire; small effect on wire size for bond strength; no effect on wire size for oxide content and hardness.

4. 85/15 vs aluminum: the 85/15 data indicates lower porosity and oxide content, lower bond strength and roughness, comparable hardness, and lower CML as compared to the aluminum data.

5. 85/15 vs zinc: the 85/15 data indicates lower porosity,

lower oxide content, substantially lower CML, higher hardness, higher bond strength, and comparable roughness as compared to the zinc data.

6. Zinc vs aluminum: the zinc data indicates lower hardness, lower bond strength, lower roughness, higher CML, and comparable porosity and oxide content relative to the aluminum data.

Statistically designed experiments were conducted for the six material systems to determine the parameter space for optimization. Effects, ANOVA, and optimization analyses were conducted for the six material systems. The Box-type statistical design of experiment methodology is an efficient means of determining broad-based factor effects on measured attributes. This methodology statistically delineates the impact of each variable on the measured coating characteristics across all combinations of other factors. By examination of the optimum levels of the process parameters a design coating can be obtained for any application. The optimum coating for this application would have in order of priority: low CML, low porosity, low oxides, high BS, low roughness, and high microhardness.

ANOVA analysis, conducted to determine the adequacy of the linear, quadratic, and cubic models, indicated that the quadratic model was more effective for all of the measured coating attributes. The derived regression equations define the process parameter-attribute relationship for each material. The diagnosis of residuals did not reveal any statistical problems in the regression analysis for any of the attributes.

For the 1/8" 85/15 coatings, CML, porosity, and bond strength are most strongly affected by spray angle, oxide content, roughness and microhardness are most strongly affected by spray distance. For the 3/16" 85/15 coatings, CML, oxide content, and bond strength are most strongly affected by spray angle, while porosity, roughness and microhardness are most strongly affected by spray distance. There is excellent correlation between the two 85/15 wire systems in terms of effects analysis, in that all the responses are strongly affected by either spray distance and/or spray angle.

For the 1/8" aluminum coatings, porosity, bond strength, roughness, and microhardness are most strongly affected by spray angle, while CML is most strongly affected by current, and oxide content by spray distance. For the 3/16" aluminum coatings, porosity, CML, roughness and microhardness are most strongly affected by current, while oxide content and bond strength are most strongly affected by spray angle. The strong dependency on current for the 3/16" wire system in terms of effects analysis indicates that a conpletely different wire melting mechanism is occuring because of the larger wire.

For the 1/8" zinc coatings porosity, CML, and microhardness are most strongly affected by spray angle, while bond strength and roughness are most strongly affected by current. All of the responses are secondarily affected by spray distance. For the 3/16" zinc coatings, porosity and roughness are most strongly affected by spray angle, while oxide content is most strongly affected by spray distance, bond strength and CML are most strongly affected by current, and hardness is most strongly affected by pressure. Only porosity and bond strength show correlation with the 1/8" zinc system.

Analysis was then conducted to determine the optimum parameters for the six coatings. This methodology involved numerical optimization to search for a combination of parameter levels that simultaneously satisfies the requirements placed on each of the responses. The assumptions used for the numerical optimization involved priority weighting only on the attributes of low CML, low porosity, and high bond strength.

The 1/8" 85/15 optimized parameters are: spray distance of 8.4", a 90° spray angle, a current of 324 amperes, and a pressure of 110 psia. The optimized parameters for 3/16" 85/15 are: spray distance of 7.7", 90° spray angle, current of 250 amperes, and pressure of 108 psia.

The 1/8" aluminum optimized process parameters are: spray distance of 6", a 90° spray angle, a current of 379 amperes, and a pressure of 90 psia. The optimized process parameters for 3/16" aluminum are: spray distance of 12", a 90° spray angle, a current of 450 amperes, and a pressure of 100 psia.

The 1/8" zinc optimized process parameters are: spray distance of 8", a 90^{o} spray angle, a current of 445 amperes, and a pressure of 103 psia. The optimized process parameters for 3/16" zinc are: spray distance of 12", a 90^{o} spray angle, a current of 450 amperes, and a pressure of 100 psia.

For all six cases, the derived predicted properties are better than the optimum coatings of this study discussed in the characterization section. Confirmation runs should be conducted in order to confirm these optimized parameters.

Multiple regression analysis was utilized to develop the relationship between the coating attributes and the coating performance (i.e. erosion resistance) in order to define the complete parameter/property/performance relationship. Regression equations were obtained to signify the erosion resistance as a function of the coating attributes. For all six wire systems the erosion resistance increases (i.e. low CML) with decreasing porosity. Lower roughness (i.e. smoother coatings) has a secondary effect on the 3/16" 85/15 system, the 1/8" aluminum system, and the 3/16" zinc system.

Recommendations for use of the TWEA process in the field were established for substrate surface preparation (i.e. cleaning, grit blasting) and coating application (i.e. gun angle, spray distance, feedrate, spray motion and speed).

The objective of this study was to demonstrate the use of thermal spray coatings for ACERL applications. The program objectives were met: the effects of various application and surface preparation parameters on the performance of 85Zn/15Al coatings have been measured, and the erosion resistance of the 85/15 coatings were shown to be superior to the zinc and aluminum coatings. The research of this study will be utilized to develop thermal spray process parameters and inspection criteria for Corps of Engineers thermal spray projects.

11.0 References

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3. Box, G. E. P., Hunter, W. G., and Hunter, J. S., Statistics for Experimenters, Wiley, 1978.

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5. Ryan, B. F., et al, Minitab, Version 8.0, Minitab, Inc., State College, Pennsylvania.

Appendix A. Results for the 1/8" 85/15 Wire System

Figures A1-A21: Photomicrographs A1-A21
Figures A22-A27: Perturbation Plots
Tables A1-A6: Design Expert Analysis
Table A7: Minitab Analysis

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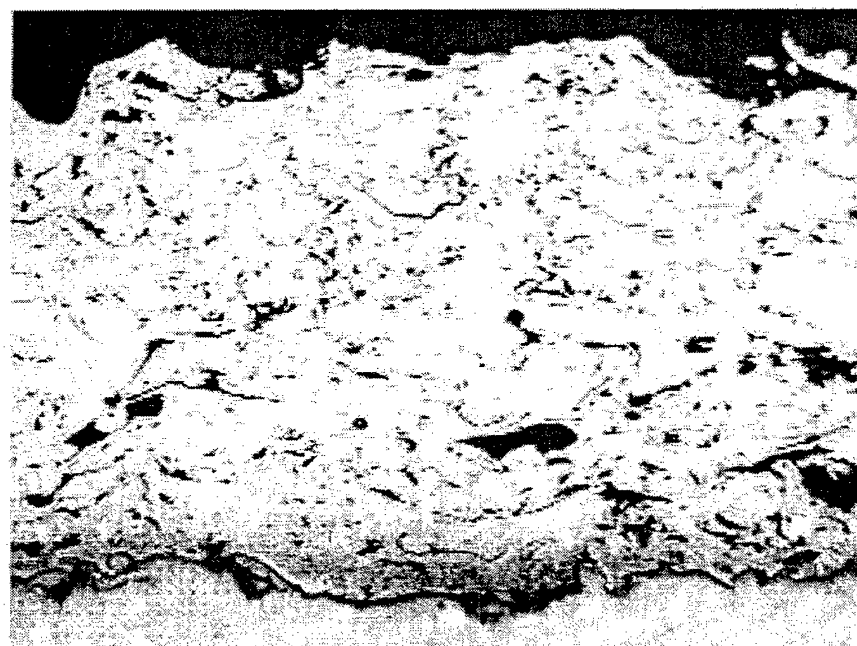

PHOTO 1 AS CAPTURED - E1 200X

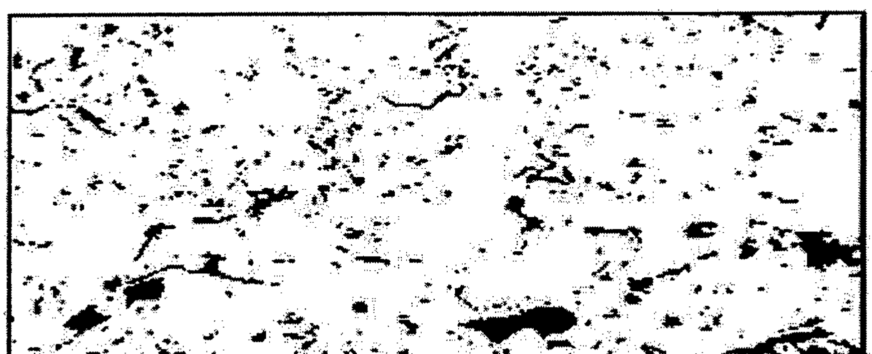

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E1

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - E1

Figure A1. Photomicrograph of Coating E1 (1/8" 85/15)

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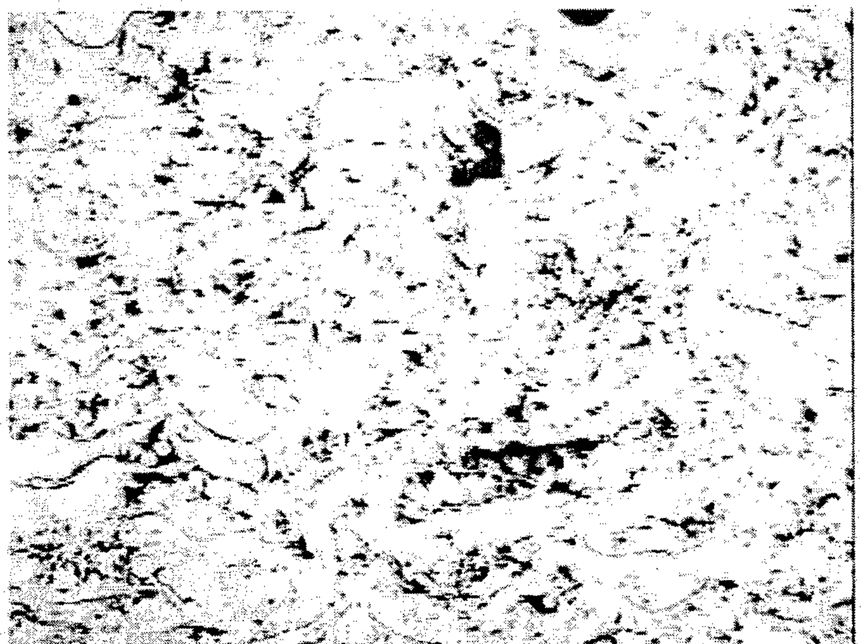

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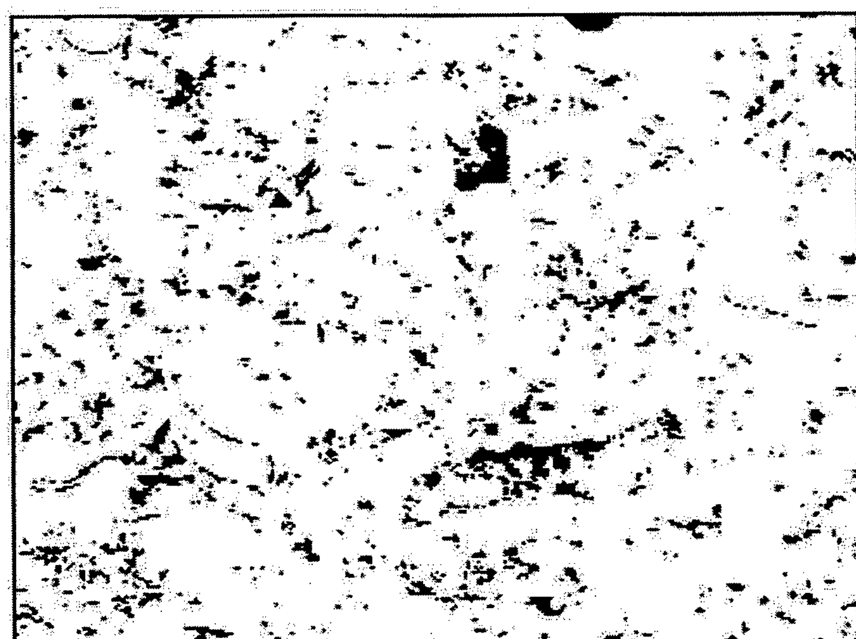

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E2

Figure A2. Photomicrograph of Coating E2 (1/8" 85/15)

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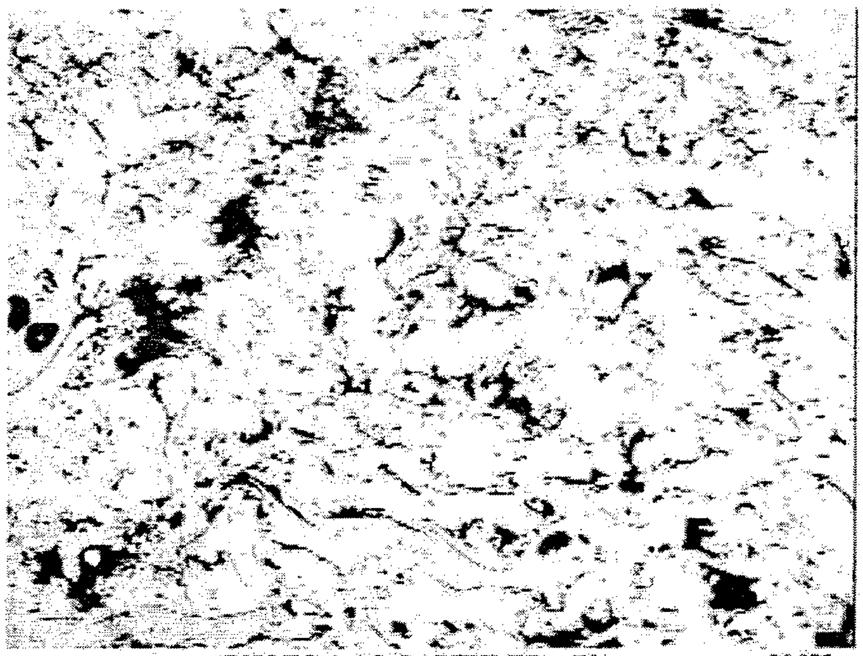

PHOTO 1 AS CAPTURED - E3 200X

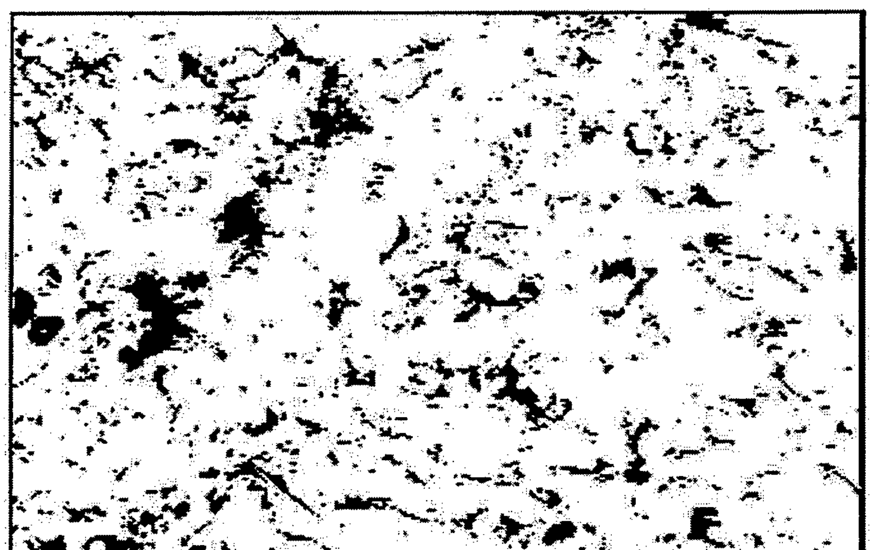

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E3

Figure A3. Photomicrograph of Coating E3 (1/8" 85/15)

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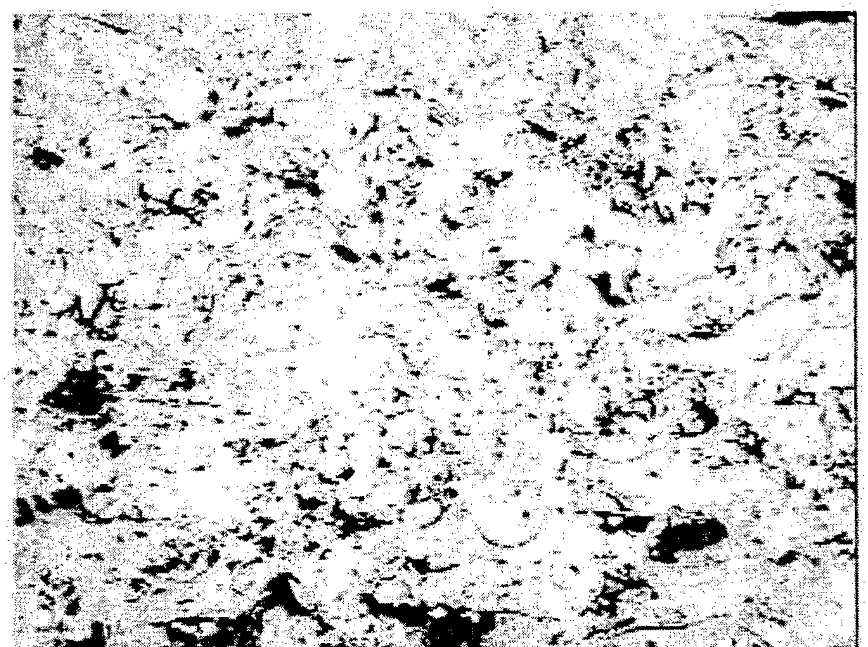

PHOTO 1 AS CAPTURED - E4 200X

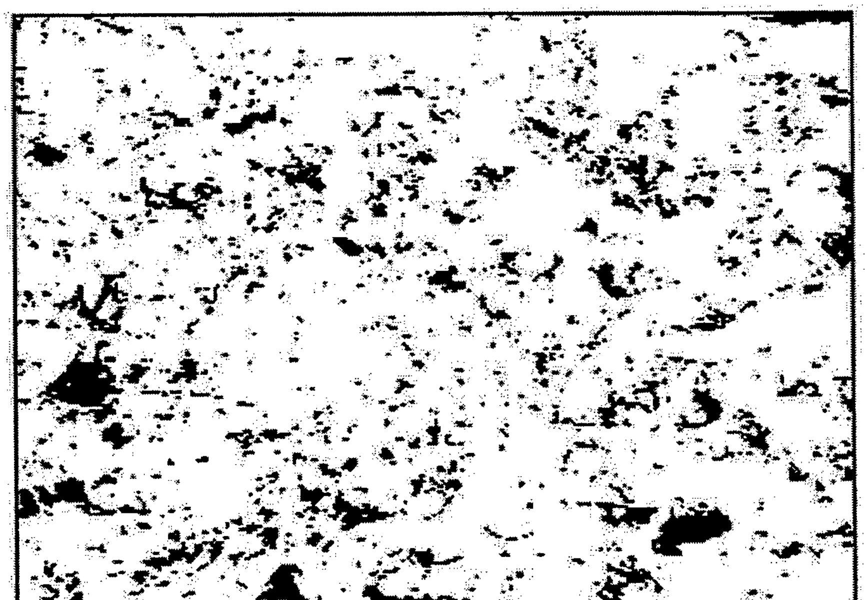

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E4

Figure A4. Photomicrograph of Coating E4 (1/8" 85/15)

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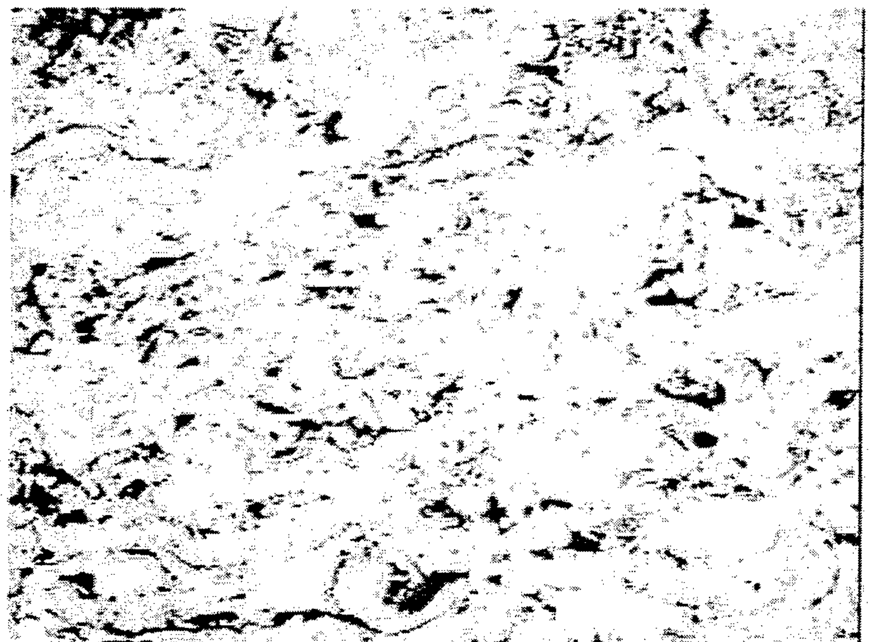

PHOTO 1 AS CAPTURED - E5 200X

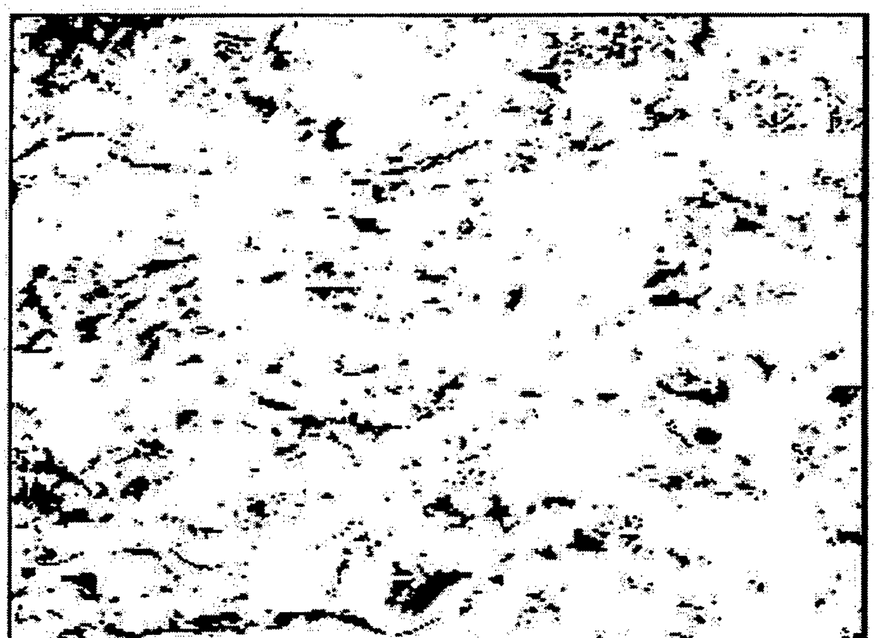

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E5

Figure A5. Photomicrograph of Coating E5 (1/8" 85/15)

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PHOTO 2 AS CAPTURED - E6 200X

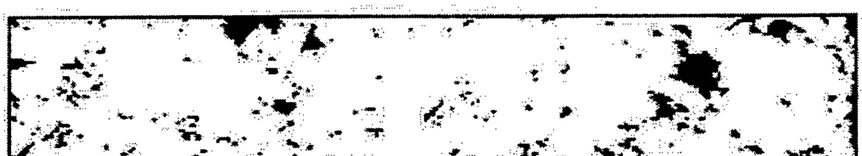

PHOTO 2 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E6

PHOTO 2 AS THRESHOLDED AND ANALYZED FOR POROSITY - E6

Figure A6. Photomicrograph of Coating E6 (1/8" 85/15)

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PHOTO 1 AS CAPTURED - E7 200X

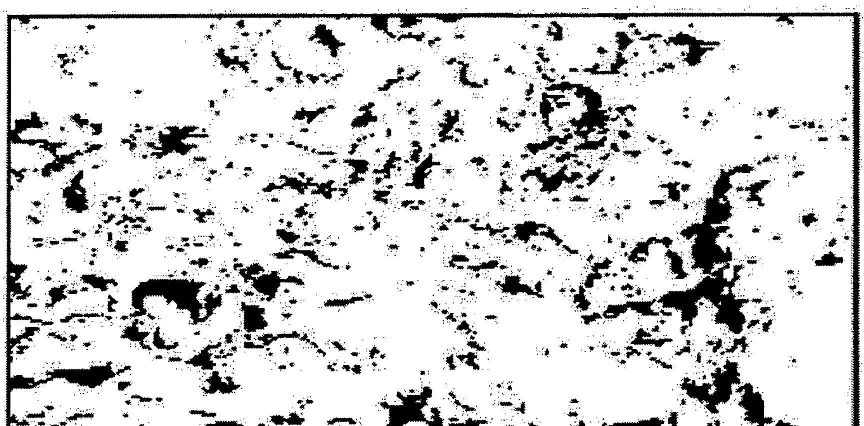

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E7

Figure A7. Photomicrograph of Coating E7 (1/8" 85/15)

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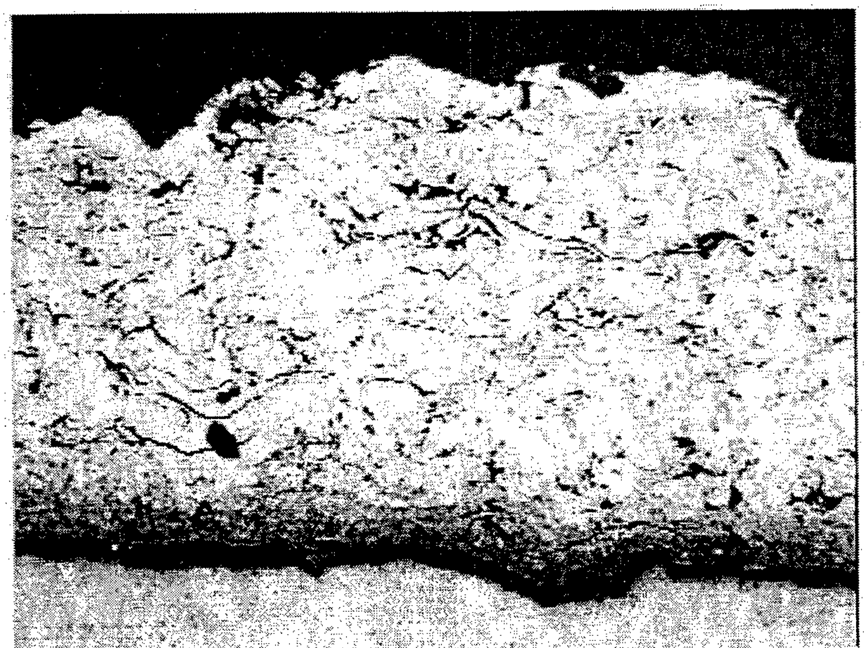

PHOTO 1 AS CAPTURED - E8 200X

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E8

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - E8

Figure A8. Photomicrograph of Coating E8 (1/8" 85/15)

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PHOTO 1 AS CAPTURED - E9 200X

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E9

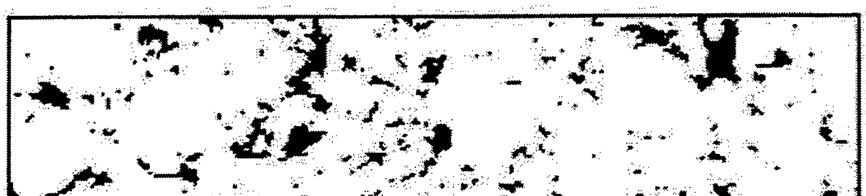

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - E9

Figure A9. Photomicrograph of Coating E9 (1/8" 85/15)

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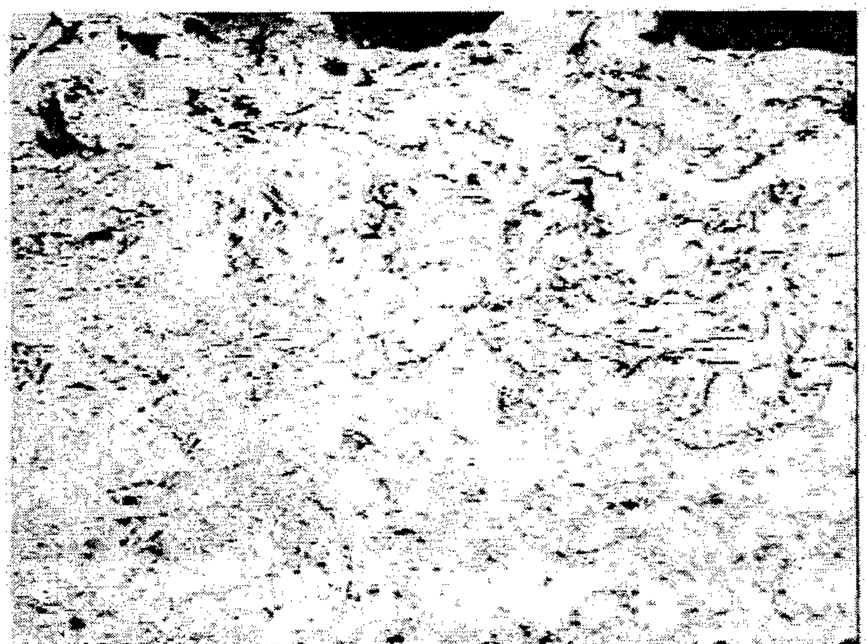

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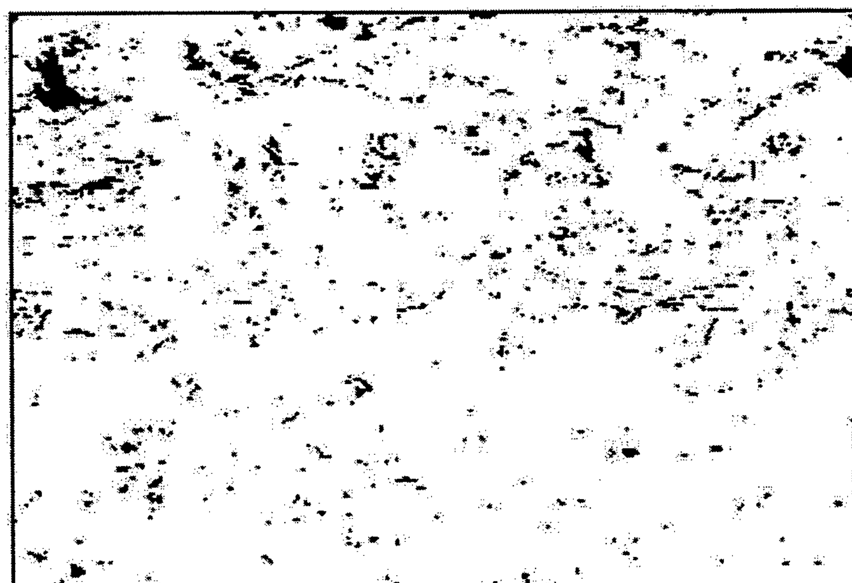

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E10

Figure A10. Photomicrograph of Coating E10 (1/8" 85/15)

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PHOTO 1 AS CAPTURED - E11 200X

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E11

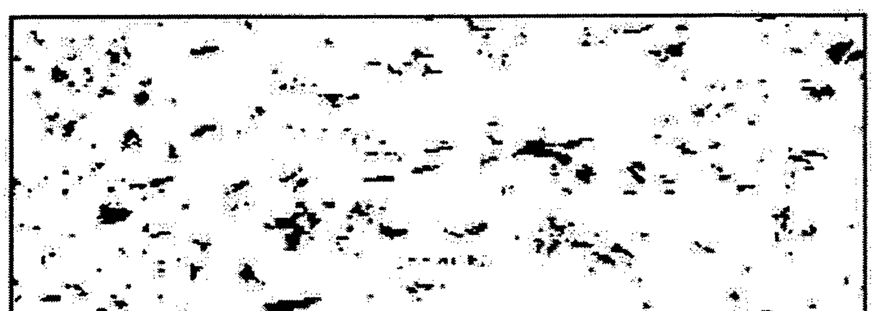

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - E11

Figure A11. Photomicrograph of Coating E11 (1/8" 85/15)

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PHOTO 1 AS CAPTURED - E12 200X

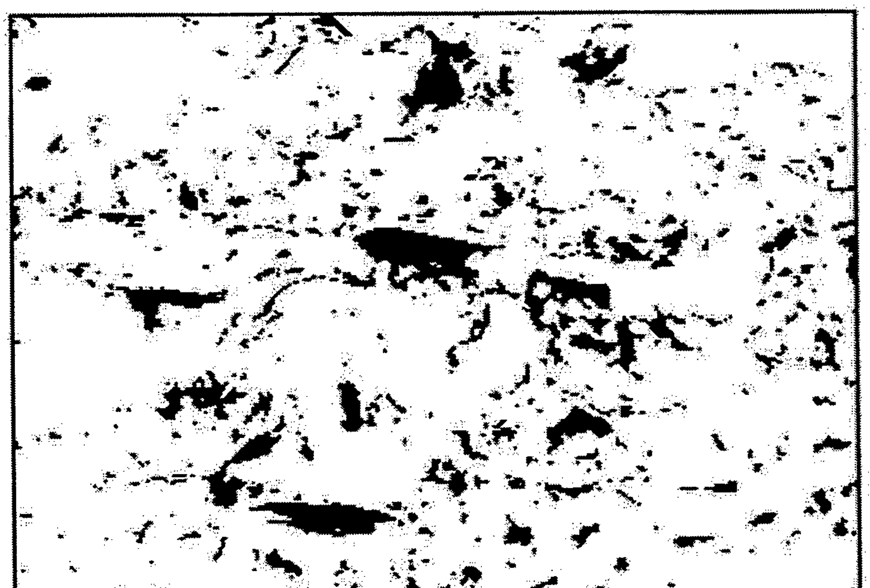

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E12

Figure A12. Photomicrograph of Coating E12 (1/8" 85/15)

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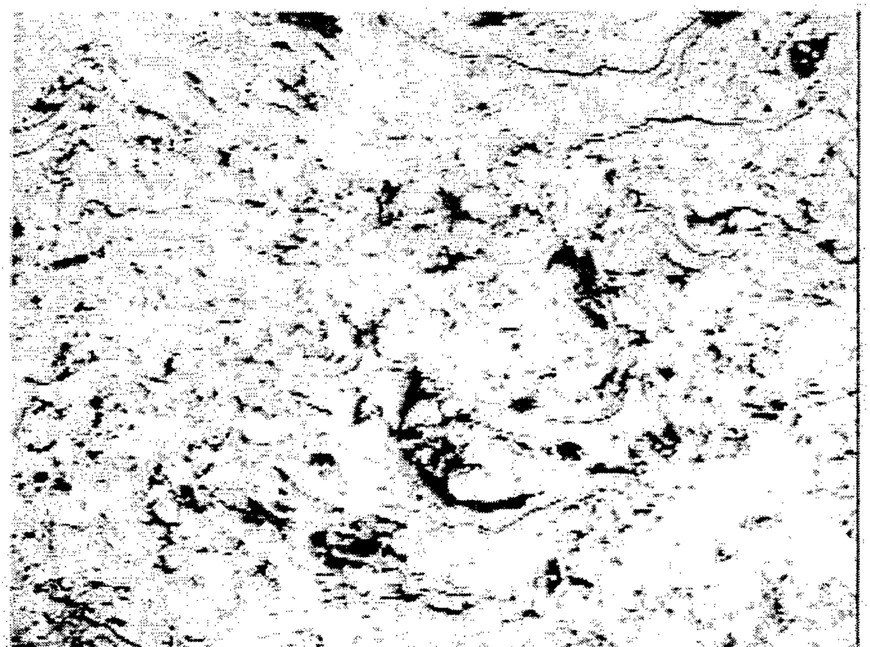

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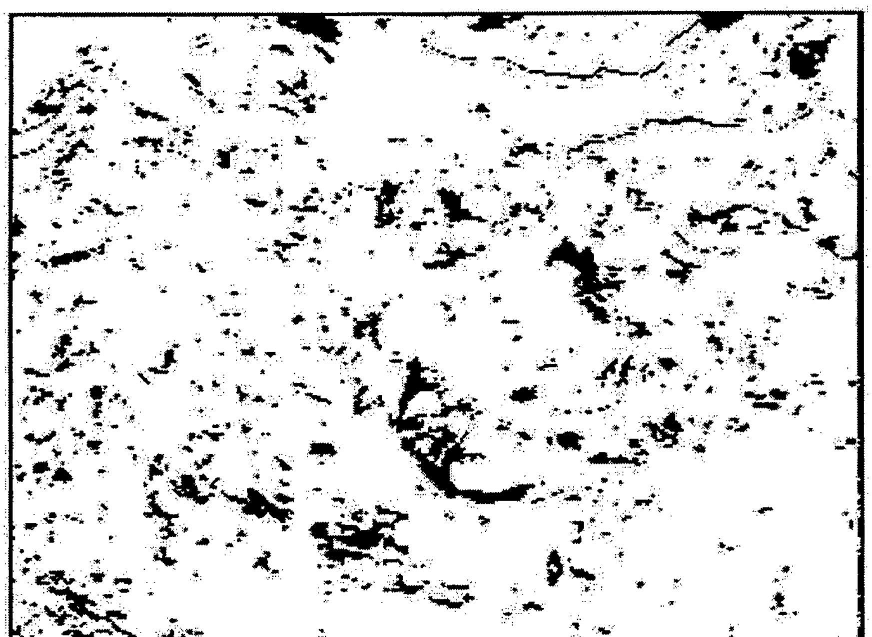

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E13

Figure A13. Photomicrograph of Coating E13 (1/8" 85/15)

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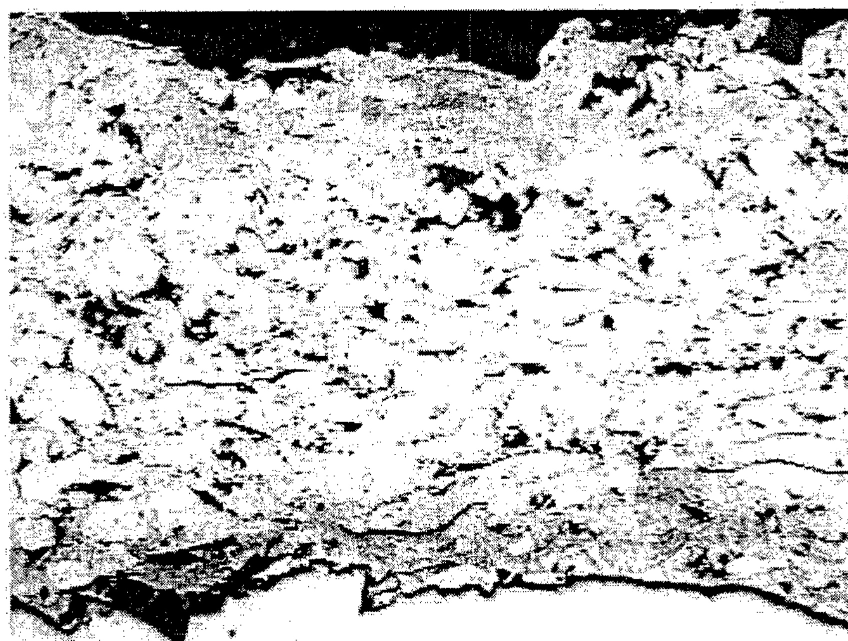

PHOTO 1 AS CAPTURED - E14 200X

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E14

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - E14

Figure A14. Photomicrograph of Coating E14 (1/8" 85/15)

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PHOTO 1 AS CAPTURED - E15 200X

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E15

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - E15

Figure A15. Photomicrograph of Coating E15 (1/8" 85/15)

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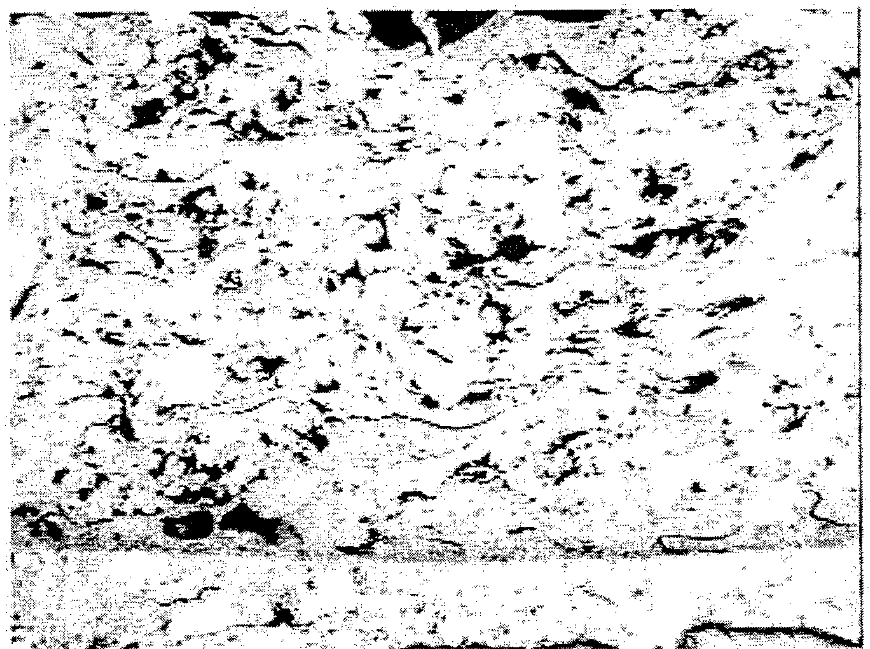

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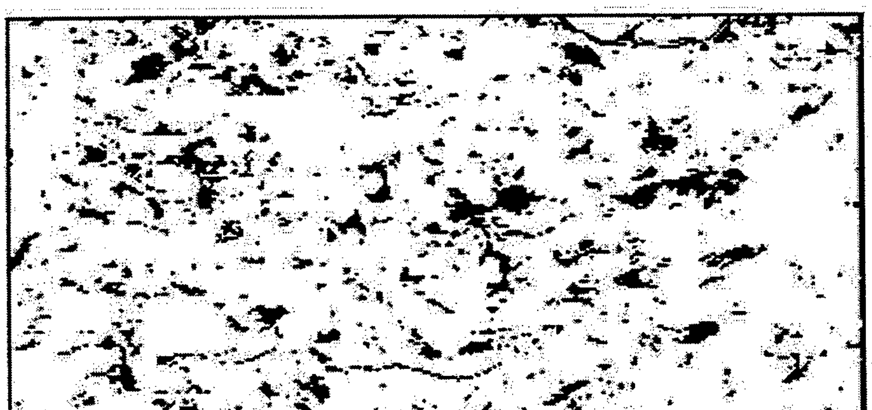

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E16

Figure A16. Photomicrograph of Coating E16 (1/8" 85/15)

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PHOTO 1 AS CAPTURED - E17 200X

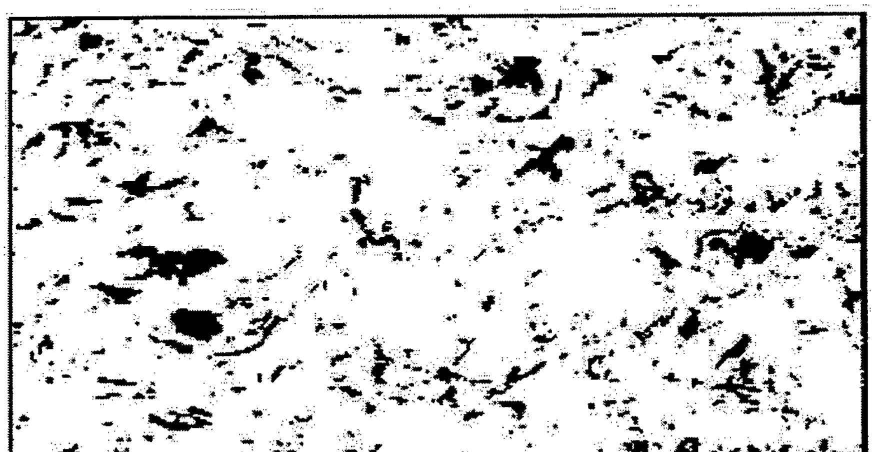

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E17

Figure A17. Photomicrograph of Coating E17 (1/8" 85/15)

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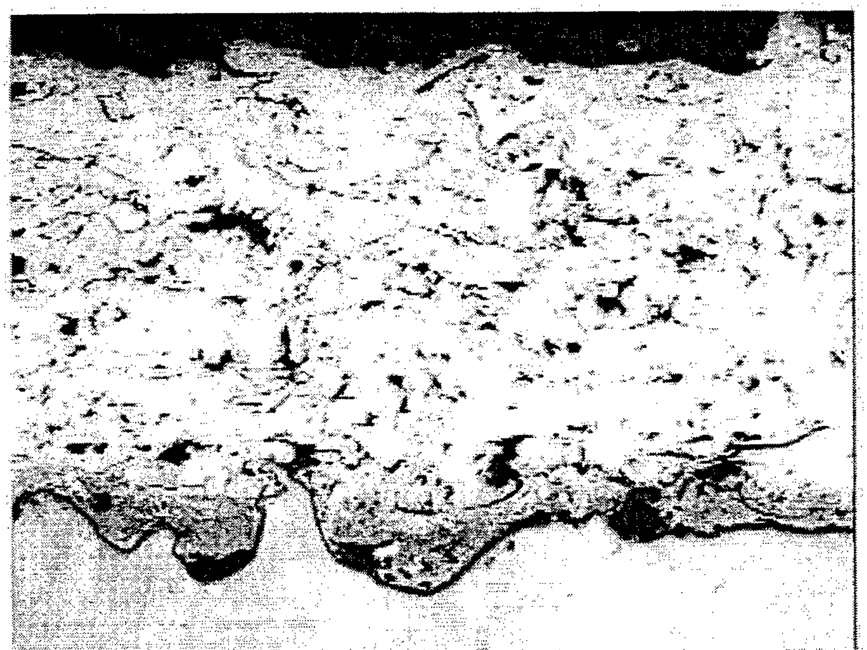

PHOTO 1 AS CAPTURED - E18 200X

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E18

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - E18

Figure A18. Photomicrograph of Coating E18 (1/8" 85/15)

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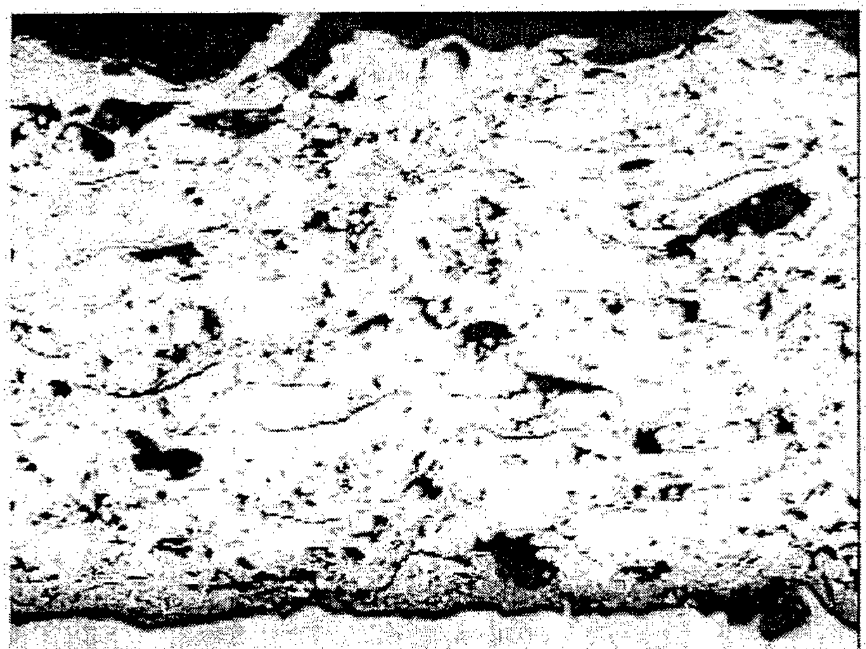

PHOTO 1 AS CAPTURED - E19 200X

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E19

Figure A19. Photomicrograph of Coating E19 (1/8" 85/15)

PROTECH LAB CORP.

Materials Testing Services

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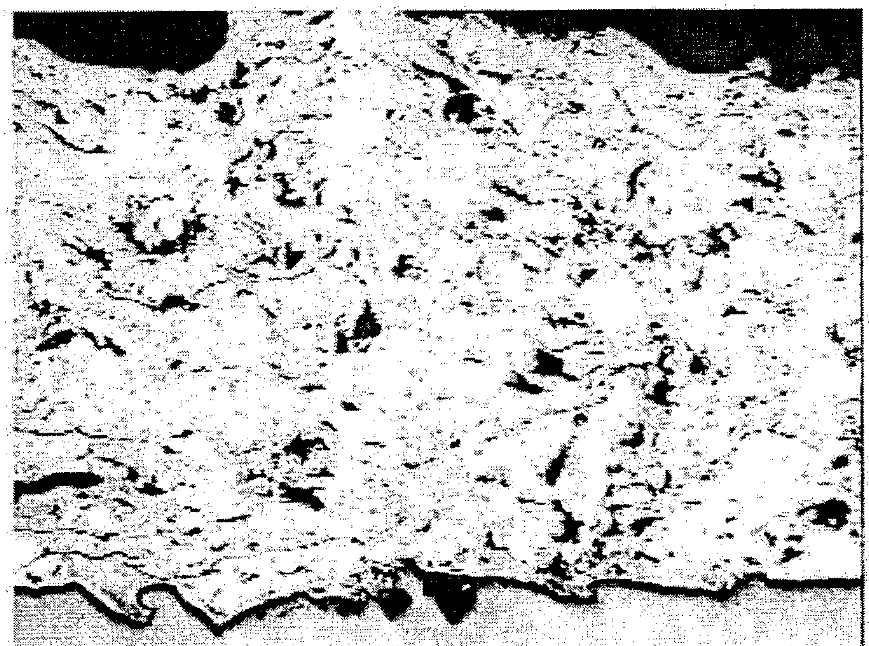


PHOTO 1 AS CAPTURED - E20 200X

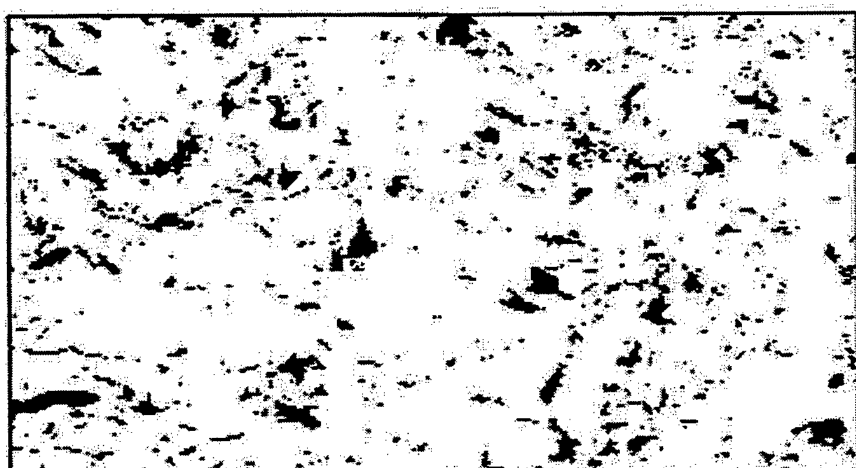


PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E20

Figure A20. Photomicrograph of Coating E20 (1/8" 85/15)

PROTECH LAB CORP.
Materials Testing Services
9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

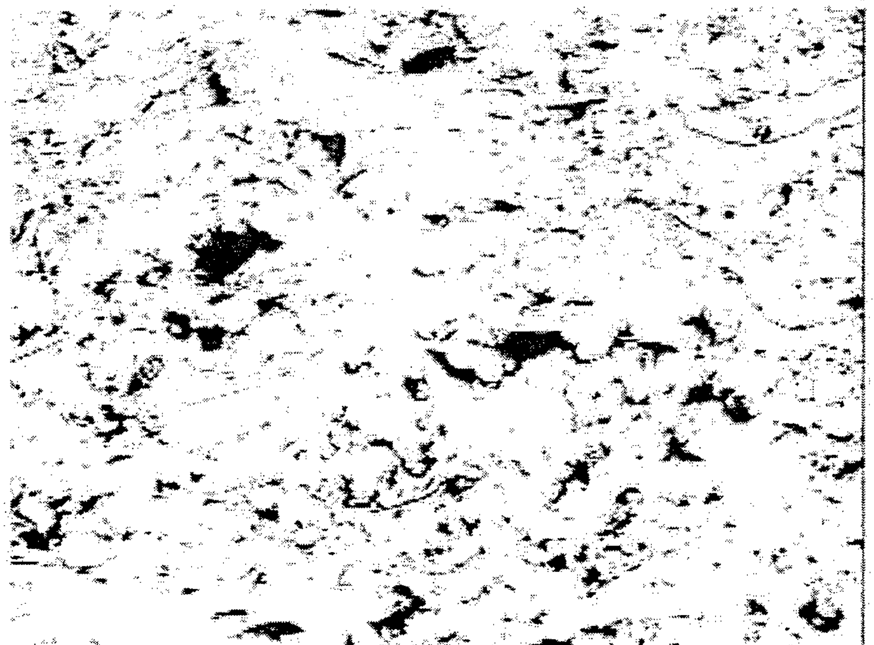


PHOTO 1 AS CAPTURED - E21 200X

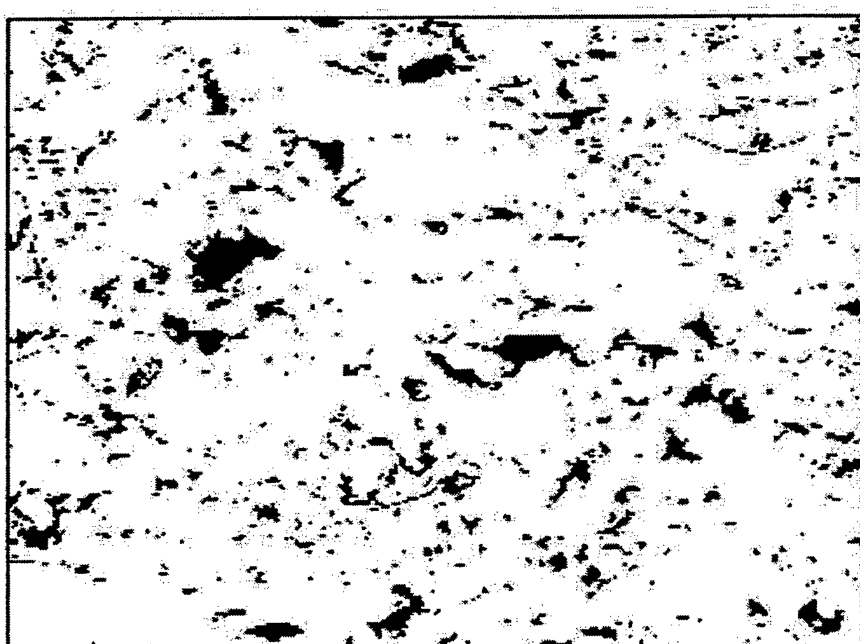
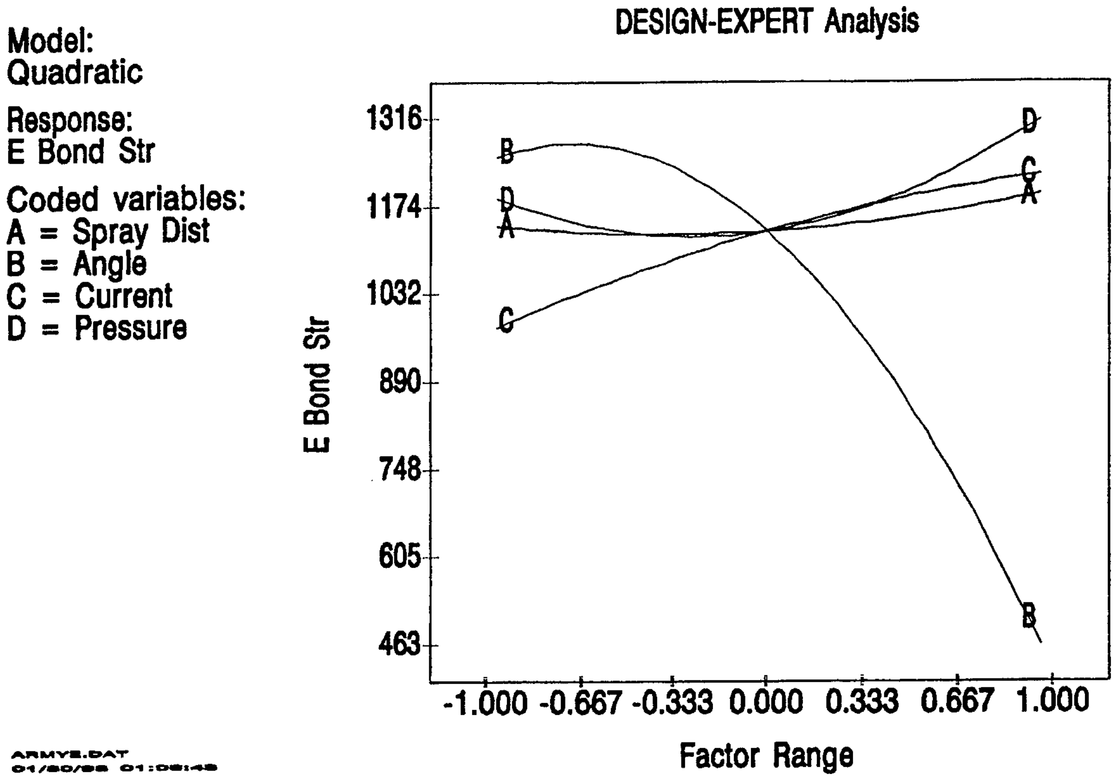


PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - E21

Figure A21. Photomicrograph of Coating E21 (1/8" 85/15)



Figures A22. Response Surface Plot of Bond Strength (E coatings)

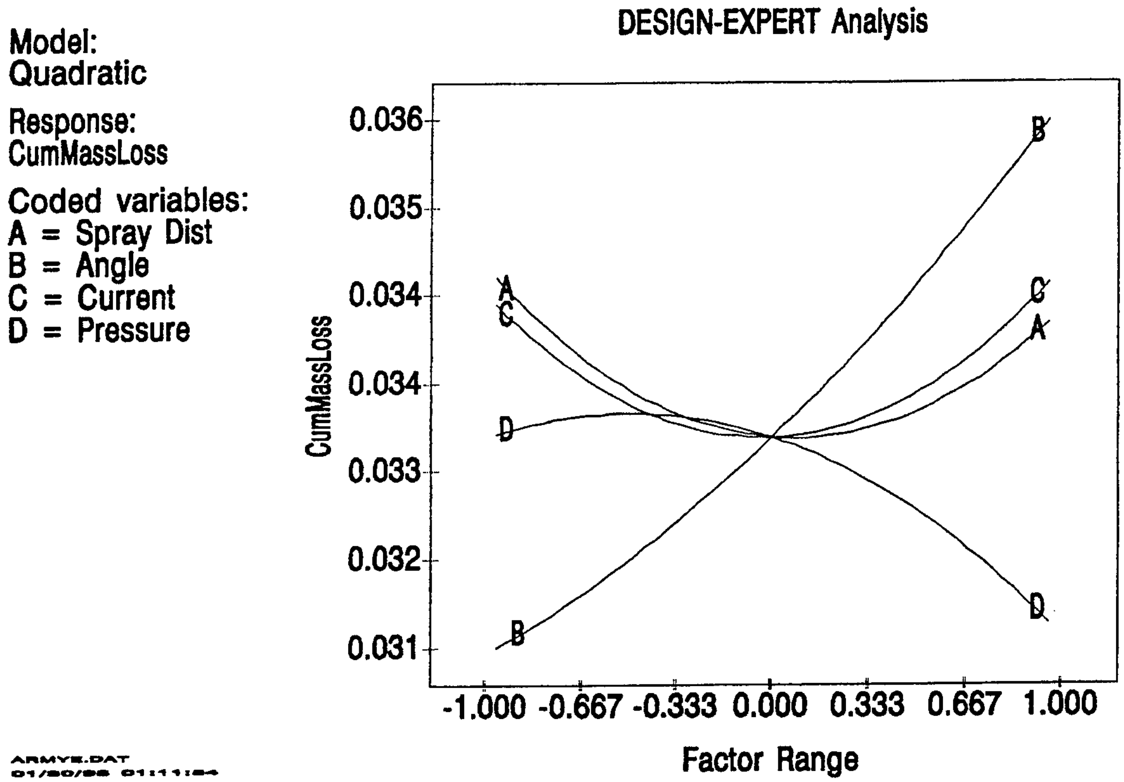


Figure A23. Response Surface Plot of CML (E coatings)

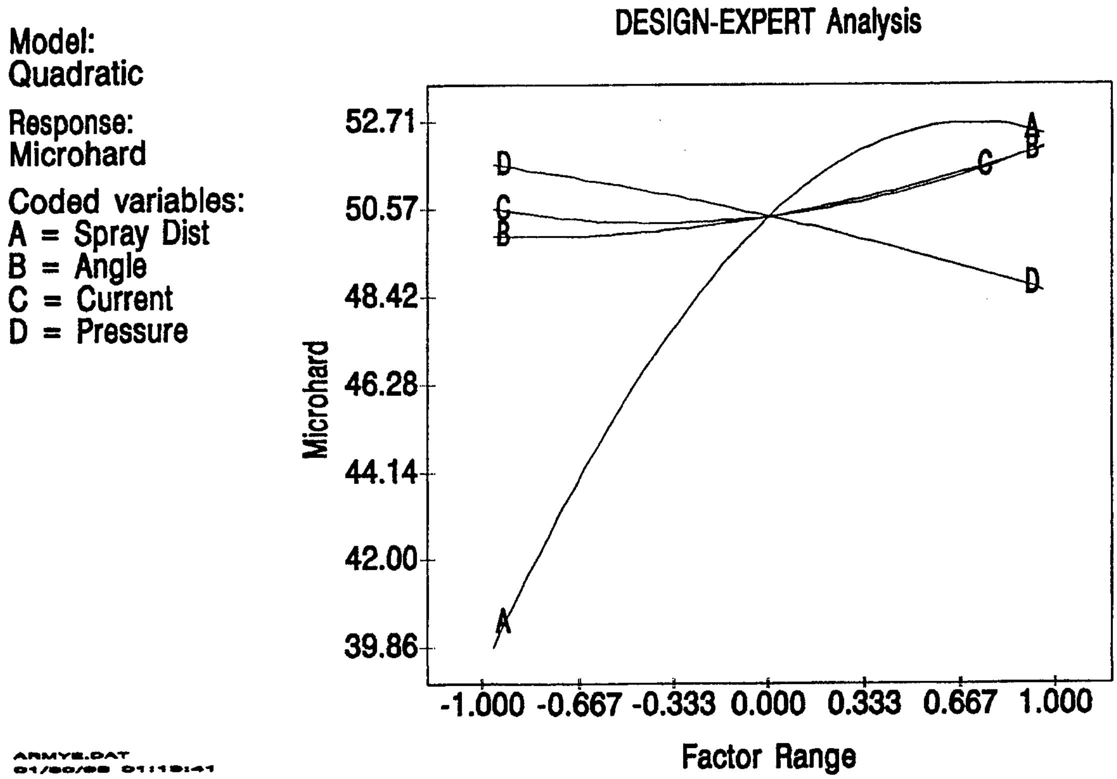


Figure A24. Response Surface Plot of Microhardness (E coatings)

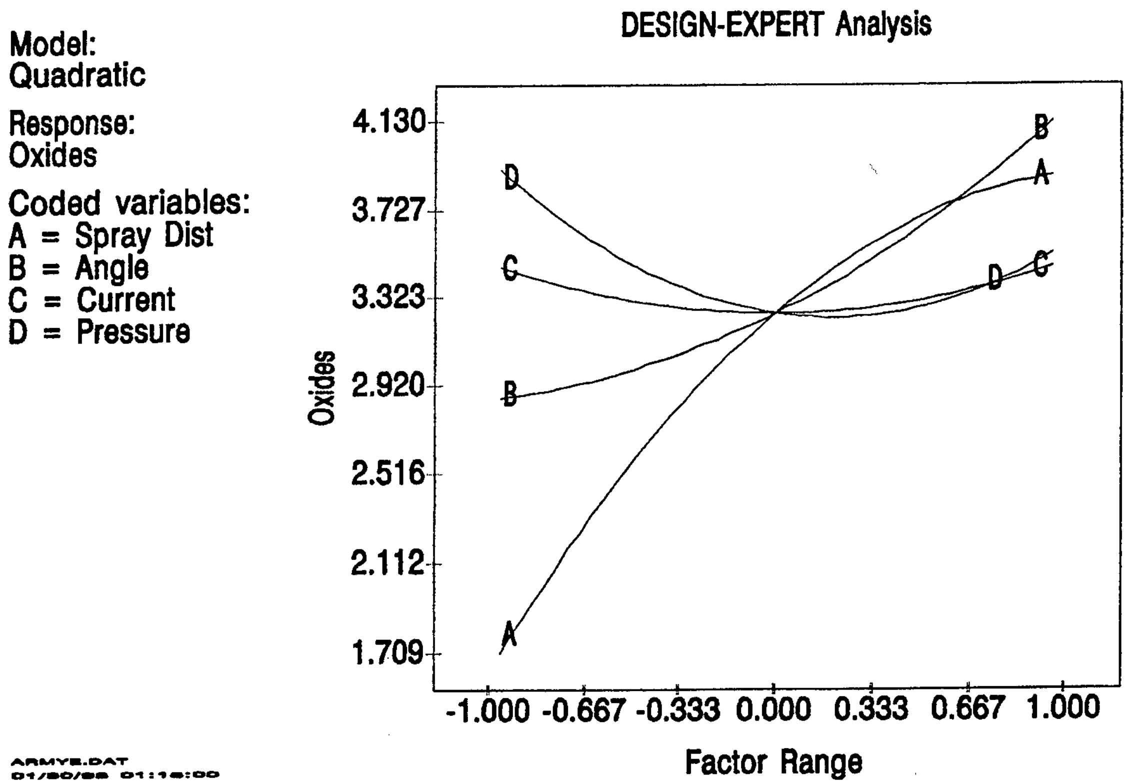


Figure A25. Response Surface Plot of Oxide Content (E coatings)

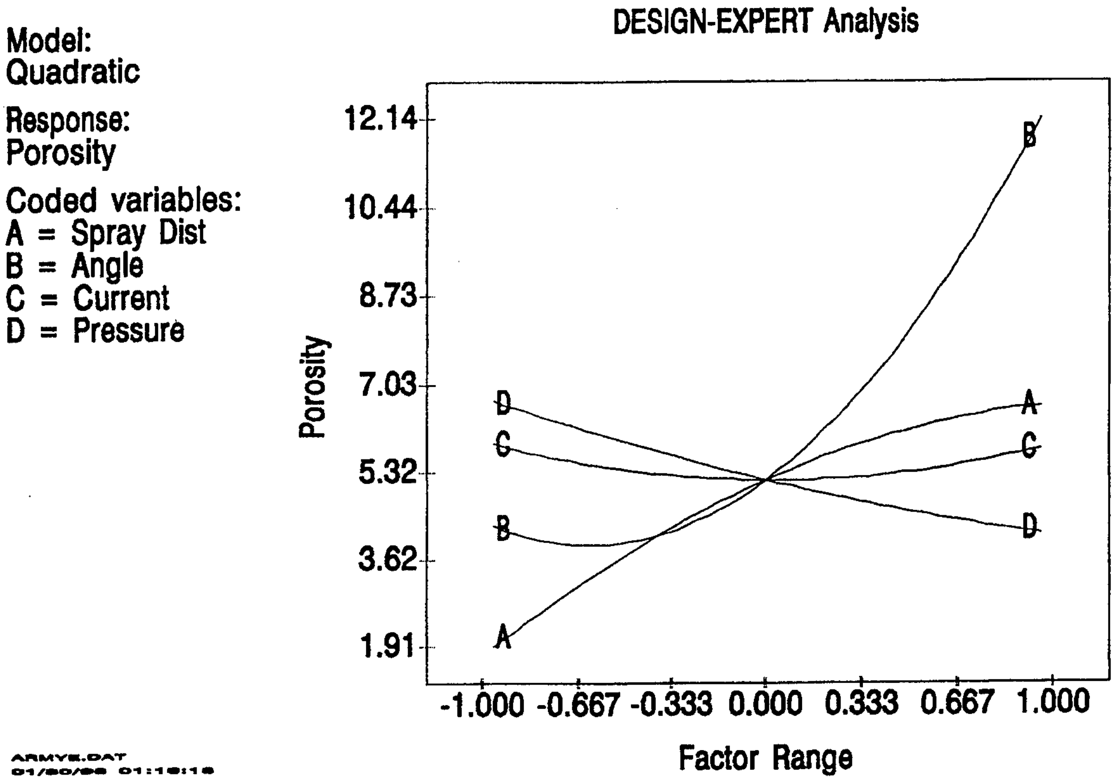


Figure A26. Response Surface Plot of Porosity (E coatings)

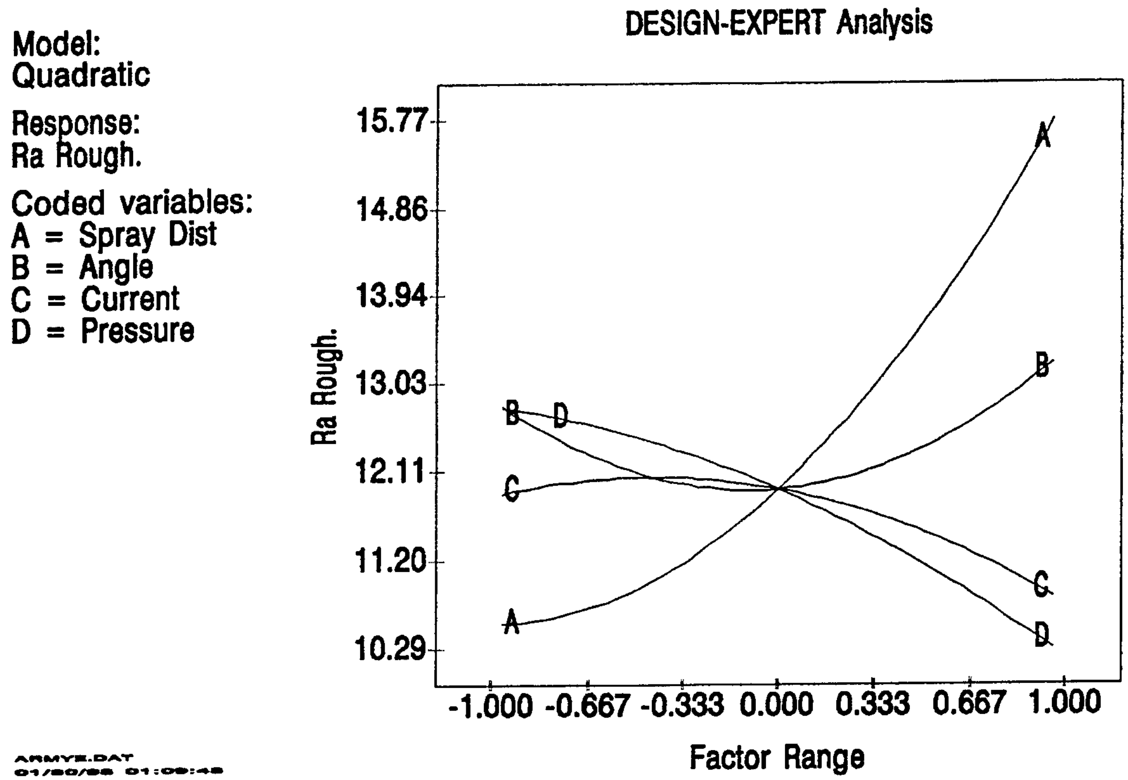


Figure A27. Response Surface Plot of Roughness (E coatings)

Table A1. 1/8" 85/15 Statistical Analysis of Bond Strength

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	26996004.8	1	26996004.8		
Linear	239985.6	4	59996.4	2.200	0.1152
Quadratic	399603.7	10	39960.4	6.532	0.0161
Cubic	5709.5	2	2854.8	0.3684	0.7131
RESIDUAL	30998.5	4	7749.6		
TOTAL	27672302.0	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	405313.2	12	33776.1	4.358	0.0834
Quadratic	5709.5	2	2854.8	0.3684	0.7131
Cubic	0.0	0			
PURE ERR	30998.5	4	7749.6		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	165.1	0.3549	0.1936	939130.9
Quadratic	15	6	78.2	0.9457	0.8191	1291808.7
Cubic	17	4	88.0	0.9542	0.7708	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	639589.2	14	45684.9	7.467	0.0105
RESIDUAL	36708.0	6	6118.0		
Lack Of Fit	5709.5	2	2854.8	0.3684	0.7131
Pure Error	30998.5	4	7749.6		
COR TOTAL	676297.2	20			

ROOT MSE	78.2	R-SQUARED	0.9457
DEP MEAN	1133.8	ADJ R-SQUARED	0.8191
C.V.	6.90%		

Predicted Residual Sum of Squares (PRESS) = 1291808.7

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	1134.9	1	29.4	38.65	
A	26.6	1	46.3	0.5751	0.5861
B	-411.7	1	145.1	-2.837	0.0297
C	127.5	1	55.3	2.305	0.0607
D	66.5	1	55.3	1.202	0.2745
A2	36.3	1	46.4	0.7820	0.4639
B2	-299.9	1	79.3	-3.782	0.0092
C2	-34.5	1	45.0	-0.7666	0.4724

D2	127.3	1	42.7	2.982	0.0246
AB	318.3	1	106.0	3.002	0.0239
AC	-178.9	1	111.3	-1.607	0.1591
AD	-331.9	1	120.3	-2.759	0.0329
BC	150.2	1	52.0	2.891	0.0276
BD	187.1	1	80.6	2.322	0.0593
CD	-92.7	1	119.2	-0.7774	0.4665

Final Equation in Terms of Actual Factors:

E Bond Str =

```
             7760.0
    +        827.03 * Spray Dist
    -        60.656 * Angle
    +        12.316 * Current
    -        190.89 * Pressure
    +        4.0362 * Spray Dist^2
    -       0.59232 * Angle      ^2
    -     3.453E-03 * Current^2
    +        1.2735 * Pressure^2
    +        4.7149 * Spray Dist * Angle
    -       0.59638 * Spray Dist * Current
    -        11.064 * Spray Dist * Pressure
    +     6.677E-02 * Angle      * Current
    +       0.83173 * Angle      * Pressure
    -     9.266E-02 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	1212.0	1207.4	4.6
2	1264.0	1144.6	119.4
3	1427.0	1435.4	-8.4
4	1284.0	1253.5	30.5
5	1386.0	1381.4	4.6
6	876.0	897.3	-21.3
7	734.0	755.3	-21.3
8	1161.0	1169.4	-8.4
9	957.0	952.4	4.6
10	1029.0	1144.6	-115.6
11	1090.0	1134.9	-44.9
12	1223.0	1197.9	25.1
13	1233.0	1246.8	-13.8
14	1100.0	1134.9	-34.9
15	784.0	758.9	25.1
16	998.0	972.9	25.1
17	1161.0	1134.9	26.1
18	1253.0	1227.9	25.1
19	1182.0	1195.8	-13.8
20	1141.0	1134.9	6.1
21	1315.0	1328.8	-13.8

□

Table A2. 1/8" 85/15 Statistical Analysis of Cumulative Mass Loss

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	0.0226386	1	0.0226386		
Linear	0.0001105	4	0.0000276	4.565	0.0119
Quadratic	0.0000649	10	0.0000065	1.222	0.4201
Cubic	0.0000152	2	0.0000076	1.810	0.2755
RESIDUAL	0.0000167	4	0.0000042		
TOTAL	0.0228459	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	0.0000801	12	0.0000067	1.595	0.3476
Quadratic	0.0000152	2	0.0000076	1.810	0.2755
Cubic	0.0000000	0			
PURE ERR	0.0000167	4	0.0000042		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	0.00246	0.5330	0.4162	0.00018
Quadratic	15	6	0.00231	0.8462	0.4873	0.00281
Cubic	17	4	0.00205	0.9193	0.5963	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	0.0001755	14	0.00001	2.358	0.1491
RESIDUAL	0.0000319	6	0.00001		
Lack Of Fit	0.0000152	2	0.00001	1.810	0.2755
Pure Error	0.0000167	4	0.00000		
COR TOTAL	0.0002073	20			

ROOT MSE	0.00231	R-SQUARED	0.8462
DEP MEAN	0.03283	ADJ R-SQUARED	0.4873
C.V.	7.02%		

Predicted Residual Sum of Squares (PRESS) = 0.0028087

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	0.03305	1	0.00087	38.18	
A	-0.00023	1	0.00137	-0.1684	0.8718
B	0.00268	1	0.00428	0.6267	0.5539
C	0.00010	1	0.00163	6.13E-02	0.9531
D	-0.00095	1	0.00163	-0.5827	0.5813
A2	0.00146	1	0.00137	1.065	0.3280

B2	0.00057	1	0.00234	0.2450	0.8146
C2	0.00153	1	0.00133	1.151	0.2937
D2	-0.00096	1	0.00126	-0.7617	0.4751
AB	-0.00510	1	0.00312	-1.633	0.1535
AC	-0.00411	1	0.00328	-1.251	0.2573
AD	0.00409	1	0.00355	1.153	0.2929
BC	0.00070	1	0.00153	0.4547	0.6653
BD	-0.00018	1	0.00238	-7.59E-02	0.9420
CD	0.00371	1	0.00351	1.057	0.3312

Final Equation in Terms of Actual Factors:

```
CumMassLoss =
                    0.12806
          -       5.022E-03 * Spray Dist
          +       5.679E-04 * Angle
          -       3.820E-04 * Current
          -       6.313E-04 * Pressure
          +       1.619E-04 * Spray Dist^2
          +       1.131E-06 * Angle     ^2
          +       1.528E-07 * Current^2
          -       9.588E-06 * Pressure^2
          -       7.561E-05 * Spray Dist * Angle
          -       1.369E-05 * Spray Dist * Current
          +       1.363E-04 * Spray Dist * Pressure
          +       3.095E-07 * Angle      * Current
          -       8.013E-07 * Angle      * Pressure
          +       3.714E-06 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	0.03370	0.03315	0.00055
2	0.03410	0.03474	-0.00064
3	0.02380	0.02387	-0.00007
4	0.03100	0.02921	0.00179
5	0.03150	0.03095	0.00055
6	0.03210	0.03280	-0.00070
7	0.03340	0.03410	-0.00070
8	0.03820	0.03827	-0.00007
9	0.03750	0.03695	0.00055
10	0.03490	0.03474	0.00016
11	0.03230	0.03305	-0.00075
12	0.03450	0.03428	0.00022
13	0.02930	0.03094	-0.00164
14	0.03620	0.03305	0.00315
15	0.03020	0.02998	0.00022
16	0.03470	0.03448	0.00022
17	0.03120	0.03305	-0.00185
18	0.03490	0.03468	0.00022
19	0.03140	0.03304	-0.00164
20	0.03510	0.03305	0.00205
21	0.02950	0.03114	-0.00164

Table A3. 1/8" 85/15 Statistical Analysis of Microhardness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	50186.1	1	50186.1		
Linear	95.3	4	23.8	1.675	0.2049
Quadratic	210.8	10	21.1	7.560	0.0111
Cubic	1.6	2	0.8	0.2084	0.8202
RESIDUAL	15.2	4	3.8		
TOTAL	50508.9	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	212.4	12	17.7	4.673	0.0744
Quadratic	1.6	2	0.8	0.2084	0.8202
Cubic	0.0	0			
PURE ERR	15.2	4	3.8		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	3.77	0.2951	0.1189	463.50
Quadratic	15	6	1.67	0.9482	0.8272	381.47
Cubic	17	4	1.95	0.9531	0.7653	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	306.1	14	21.86	7.840	0.0092
RESIDUAL	16.7	6	2.79		
Lack Of Fit	1.6	2	0.79	0.2084	0.8202
Pure Error	15.2	4	3.79		
COR TOTAL	322.8	20			
ROOT MSE	1.67		R-SQUARED	0.9482	
DEP MEAN	48.89		ADJ R-SQUARED	0.8272	
C.V.	3.42%				

Predicted Residual Sum of Squares (PRESS) = 381.5

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	50.39	1	0.63	80.37	
A	6.54	1	0.99	6.613	0.0006
B	1.14	1	3.10	0.3669	0.7263
C	0.80	1	1.18	0.6775	0.5233
D	-1.60	1	1.18	-1.355	0.2242
A2	-4.61	1	0.99	-4.647	0.0035
B2	0.65	1	1.69	0.3849	0.7136
C2	1.03	1	0.96	1.074	0.3243

D2	-0.29	1	0.91	-0.3131	0.7648
AB	-1.56	1	2.26	-0.6893	0.5164
AC	-5.87	1	2.38	-2.470	0.0485
AD	6.16	1	2.57	2.398	0.0535
BC	-1.10	1	1.11	-0.9899	0.3604
BD	-0.10	1	1.72	-5.61E-02	0.9570
CD	12.30	1	2.54	4.834	0.0029

Final Equation in Terms of Actual Factors:

Microhard =
508.15
- 0.20637 * Spray Dist
+ 0.24063 * Angle
- 1.0742 * Current
- 5.7032 * Pressure
- 0.51206 * Spray Dist^2
+ 1.287E-03 * Angle ^2
+ 1.032E-04 * Current^2
- 2.855E-03 * Pressure^2
- 2.312E-02 * Spray Dist * Angle
- 1.956E-02 * Spray Dist * Current
+ 0.20531 * Spray Dist * Pressure
- 4.880E-04 * Angle * Current
- 4.295E-04 * Angle * Pressure
+ 1.230E-02 * Current * Pressure

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	50.00	50.13	-0.13
2	41.80	39.24	2.56
3	50.90	50.79	0.11
4	47.50	48.11	-0.61
5	41.10	41.23	-0.13
6	49.10	48.75	0.35
7	50.80	50.45	0.35
8	50.50	50.39	0.11
9	50.60	50.73	-0.13
10	36.70	39.24	-2.54
11	50.10	50.39	-0.29
12	52.00	52.32	-0.32
13	50.30	49.90	0.40
14	49.40	50.39	-0.99
15	50.40	50.72	-0.32
16	50.30	50.62	-0.32
17	51.30	50.39	0.91
18	51.90	52.22	-0.32
19	52.10	51.70	0.40
20	50.90	50.39	0.51
21	48.90	48.50	0.40

Table A4. 1/8" 85/15 Statistical Analysis of Oxide Content

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	217.61	1	217.61		
Linear	1.32	4	0.33	0.4268	0.7872
Quadratic	9.47	10	0.95	1.967	0.2106
Cubic	1.62	2	0.81	2.539	0.1942
RESIDUAL	1.27	4	0.32		
TOTAL	231.28	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	11.08	12	0.92	2.903	0.1572
Quadratic	1.62	2	0.81	2.539	0.1942
Cubic	0.00	0			
PURE ERR	1.27	4	0.32		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	0.879	0.0964	-0.1295	25.883
Quadratic	15	6	0.694	0.7888	0.2960	337.978
Cubic	17	4	0.564	0.9069	0.5346	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	10.78	14	0.770	1.601	0.2918
RESIDUAL	2.89	6	0.481		
Lack Of Fit	1.62	2	0.808	2.539	0.1942
Pure Error	1.27	4	0.318		
COR TOTAL	13.67	20			

ROOT MSE	0.694	R-SQUARED	0.7888
DEP MEAN	3.219	ADJ R-SQUARED	0.2960
C.V.	21.55%		

Predicted Residual Sum of Squares (PRESS) = 337.98

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	3.255	1	0.260	12.50	
A	1.132	1	0.411	2.754	0.0331
B	0.660	1	1.287	0.5123	0.6267
C	-9.496E-17	1	0.491	-1.94E-16	1.0000
D	-0.200	1	0.491	-0.4077	0.6976
A2	-0.499	1	0.412	-1.211	0.2715
B2	0.263	1	0.703	0.3740	0.7213

C2	0.233	1	0.400	0.5831	0.5811
D2	0.503	1	0.379	1.329	0.2321
AB	-0.066	1	0.940	-6.97E-02	0.9467
AC	0.241	1	0.987	0.2442	0.8152
AD	0.432	1	1.067	0.4044	0.6999
BC	-0.130	1	0.461	-0.2820	0.7874
BD	-0.405	1	0.715	-0.5665	0.5916
CD	1.977	1	1.057	1.871	0.1106

Final Equation in Terms of Actual Factors:

```
Oxides =
              118.026
     -        0.25761 * Spray Dist
     +        0.14476 * Angle
     -        0.21609 * Current
     -         1.6866 * Pressure
     -      5.542E-02 * Spray Dist^2
     +      5.195E-04 * Angle       ^2
     +      2.330E-05 * Current^2
     +      5.035E-03 * Pressure^2
     -      9.714E-04 * Spray Dist * Angle
     +      8.035E-04 * Spray Dist * Current
     +      1.439E-02 * Spray Dist * Pressure
     -      5.776E-05 * Angle       * Current
     -      1.800E-03 * Angle       * Pressure
     +      1.977E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	4.300	4.214	0.086
2	1.300	1.624	-0.324
3	4.000	4.137	-0.137
4	4.100	3.567	0.533
5	2.300	2.214	0.086
6	2.600	2.961	-0.361
7	3.800	4.161	-0.361
8	2.500	2.637	-0.137
9	3.300	3.214	0.086
10	2.000	1.624	0.376
11	3.400	3.255	0.145
12	4.300	3.888	0.412
13	2.600	2.858	-0.258
14	2.400	3.255	-0.855
15	3.400	2.988	0.412
16	3.900	3.488	0.412
17	3.700	3.255	0.445
18	3.900	3.488	0.412
19	3.700	3.958	-0.258
20	2.800	3.255	-0.455
21	3.300	3.558	-0.258

□

Table A5. 1/8" 85/15 Statistical Analysis of Porosity

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	752.4	1	752.4		
Linear	102.4	4	25.6	11.23	0.0002
Quadratic	34.9	10	3.5	13.64	0.0023
Cubic	1.1	2	0.6	5.829	0.0653
RESIDUAL	0.4	4	0.1		
TOTAL	891.2	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	36.1	12	3.0	30.63	0.0023
Quadratic	1.1	2	0.6	5.829	0.0653
Cubic	0.0	0			
PURE ERR	0.4	4	0.1		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	1.51	0.7374	0.6717	72.08
Quadratic	15	6	0.51	0.9889	0.9631	193.78
Cubic	17	4	0.31	0.9972	0.9859	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	137.3	14	9.80	38.29	0.0001
RESIDUAL	1.5	6	0.26		
Lack Of Fit	1.1	2	0.57	5.829	0.0653
Pure Error	0.4	4	0.10		
COR TOTAL	138.8	20			

ROOT MSE	0.51	R-SQUARED	0.9889
DEP MEAN	5.99	ADJ R-SQUARED	0.9631
C.V.	8.45%		

Predicted Residual Sum of Squares (PRESS) = 193.8

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	5.18	1	0.19	27.25	
A	2.45	1	0.30	8.161	0.0002
B	4.08	1	0.94	4.347	0.0048
C	-0.05	1	0.36	-0.1397	0.8934
D	-1.35	1	0.36	-3.773	0.0093
A2	-0.99	1	0.30	-3.301	0.0164
B2	3.30	1	0.51	6.442	0.0007
C2	0.70	1	0.29	2.417	0.0521
D2	0.27	1	0.28	0.9867	0.3619
AB	-0.28	1	0.69	-0.4100	0.6960

AC	0.64	1	0.72	0.8842	0.4106
AD	0.64	1	0.78	0.8205	0.4433
BC	0.18	1	0.34	0.5361	0.6112
BD	-1.30	1	0.52	-2.491	0.0471
CD	2.72	1	0.77	3.528	0.0124

Final Equation in Terms of Actual Factors:

Porosity =

```
          143.26
+       0.30275 * Spray Dist
-       0.40667 * Angle
-       0.34813 * Current
-        1.3043 * Pressure
-       0.11024 * Spray Dist^2
+     6.527E-03 * Angle      ^2
+     7.042E-05 * Current^2
+     2.726E-03 * Pressure^2
-     4.166E-03 * Spray Dist * Angle
+     2.123E-03 * Spray Dist * Current
+     2.129E-02 * Spray Dist * Pressure
+     8.009E-05 * Angle       * Current
-     5.774E-03 * Angle       * Pressure
+     2.720E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	6.00	5.93	0.07
2	1.90	1.74	0.16
3	9.60	9.49	0.11
4	4.60	4.62	-0.02
5	4.80	4.73	0.07
6	11.50	11.35	0.15
7	7.40	7.25	0.15
8	3.70	3.59	0.11
9	10.70	10.63	0.07
10	1.40	1.74	-0.34
11	5.90	5.18	0.72
12	6.30	6.63	-0.33
13	4.20	4.40	-0.20
14	5.60	5.18	0.42
15	9.90	10.23	-0.33
16	5.60	5.93	-0.33
17	5.40	5.18	0.22
18	5.50	5.83	-0.33
19	6.60	6.80	-0.20
20	5.20	5.18	0.02
21	3.90	4.10	-0.20

□

Table A6. 1/8" 85/15 Statistical Analysis of Roughness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	3562.3	1	3562.3		
Linear	125.0	4	31.3	8.480	0.0007
Quadratic	32.1	10	3.2	0.7171	0.6942
Cubic	7.9	2	4.0	0.8401	0.4959
RESIDUAL	18.9	4	4.7		
TOTAL	3746.2	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	40.1	12	3.3	0.7058	0.7129
Quadratic	7.9	2	4.0	0.8401	0.4959
Cubic	0.0	0			
PURE ERR	18.9	4	4.7		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	1.92	0.6795	0.5993	93.50
Quadratic	15	6	2.12	0.8540	0.5133	1482.85
Cubic	17	4	2.17	0.8972	0.4859	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	157.1	14	11.22	2.507	0.1324
RESIDUAL	26.9	6	4.48		
Lack Of Fit	7.9	2	3.97	0.8401	0.4959
Pure Error	18.9	4	4.73		
COR TOTAL	184.0	20			

ROOT MSE	2.12	R-SQUARED	0.8540
DEP MEAN	13.02	ADJ R-SQUARED	0.5133
C.V.	16.25%		

Predicted Residual Sum of Squares (PRESS) = 1482.9

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	11.93	1	0.79	15.02	
A	2.71	1	1.25	2.165	0.0735
B	0.24	1	3.93	6.05E-02	0.9537
C	-0.55	1	1.50	-0.3676	0.7258
D	-1.30	1	1.50	-0.8655	0.4200
A2	1.34	1	1.26	1.065	0.3277

B2	1.18	1	2.14	0.5487	0.6030
C2	-0.62	1	1.22	-0.5068	0.6303
D2	-0.44	1	1.16	-0.3771	0.7191
AB	5.57	1	2.87	1.941	0.1003
AC	4.09	1	3.01	1.358	0.2232
AD	-3.91	1	3.25	-1.201	0.2749
BC	1.17	1	1.41	0.8334	0.4365
BD	2.23	1	2.18	1.023	0.3459
CD	-4.44	1	3.22	-1.377	0.2175

Final Equation in Terms of Actual Factors:

Ra Rough. =

	-59.93	
-	0.93378	* Spray Dist
-	2.3234	* Angle
+	0.31228	* Current
+	2.5771	* Pressure
+	0.14874	* Spray Dist^2
+	2.325E-03	* Angle ^2
-	6.176E-05	* Current^2
-	4.357E-03	* Pressure^2
+	8.245E-02	* Spray Dist * Angle
+	1.363E-02	* Spray Dist * Current
-	0.13032	* Spray Dist * Pressure
+	5.206E-04	* Angle * Current
+	9.912E-03	* Angle * Pressure
-	4.441E-03	* Current * Pressure

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	17.39	16.99	0.40
2	11.52	10.56	0.96
3	11.55	11.60	-0.05
4	10.19	8.91	1.28
5	16.46	16.06	0.40
6	17.95	18.44	-0.49
7	12.62	13.11	-0.49
8	10.58	10.63	-0.05
9	18.71	18.31	0.40
10	9.24	10.56	-1.32
11	10.80	11.93	-1.13
12	16.12	15.98	0.14
13	11.68	12.87	-1.19
14	10.09	11.93	-1.84
15	16.30	16.16	0.14
16	12.00	11.86	0.14
17	13.94	11.93	2.01
18	10.90	10.76	0.14
19	11.60	12.79	-1.19
20	14.86	11.93	2.93
21	9.01	10.20	-1.19

Table A7. Minitab Analysis for 1/8" 85/15

```
MTB > regress c6 20 c1-c5 c7-c21;
SUBC> residuals c22.
```

The regression equation is

CML = 0.505 - 0.00324 P - 0.0261 O - 0.0181 MH -0.000000 BS2 +0.000077 R2 +0.000140 P2 + 0.00385 O2 +0.000196 MH2 - 21.5 1/BS + 0.386 1/R - 0.0055 1/O - 0.0697 1/P2

Predictor	Coef	Stdev	t-ratio	p
Constant	0.5053	0.2331	2.17	0.062
P	-0.003244	0.003971	-0.82	0.438
O	-0.02611	0.02460	-1.06	0.319
MH	-0.018106	0.009295	-1.95	0.087
BS2	-0.00000002	0.00000001	-2.53	0.035
R2	0.00007669	0.00003761	2.04	0.076
P2	0.0001404	0.0002510	0.56	0.591
O2	0.003854	0.003114	1.24	0.251
MH2	0.00019572	0.00009894	1.98	0.083
1/BS	-21.54	14.23	-1.51	0.168
1/R	0.3856	0.1802	2.14	0.065
1/O	-0.00549	0.04529	-0.12	0.907
1/P2	-0.06974	0.03903	-1.79	0.112

s = 0.002278 R-sq = 80.0% R-sq(adj) = 49.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	12	0.000165832	0.000013819	2.66	0.086
Error	8	0.000041514	0.000005189		
Total	20	0.000207347			

SOURCE	DF	SEQ SS
P	1	0.000010337
O	1	0.000006630
MH	1	0.000008108
BS2	1	0.000051745
R2	1	0.000029333
P2	1	0.000000070
O2	1	0.000000858
MH2	1	0.000001807
1/BS	1	0.000020489
1/R	1	0.000019590
1/O	1	0.000000300
1/P2	1	0.000016566

Unusual Observations

Obs.	P	CML	Fit	Stdev.Fit	Residual	St.Resid
2	1.9	0.034100	0.034119	0.002278	-0.000019	-0.43 X
5	4.8	0.031500	0.031394	0.002267	0.000106	0.48 X
10	1.4	0.034900	0.034924	0.002277	-0.000024	-0.46 X

X denotes an obs. whose X value gives it large influence.

RESIDUALS

-0.0003676	-0.0000192	0.0011216	0.0011059	0.0001059	-0.0017612
0.0008972	0.0024029	0.0025131	-0.0000238	-0.0003644	-0.0012089
-0.0023830	-0.0000539	-0.0012098	0.0003776	-0.0009993	0.0011813
-0.0019405	0.0022690	-0.0016429			

Appendix B. Results for the 3/16" 85/15 Wire System

Figures B1-B21: Photomicrographs B1-B21
Figures B22-B27: Perturbation Plots
Tables B1-B6: Design Expert Analysis
Table B7: Minitab Analysis

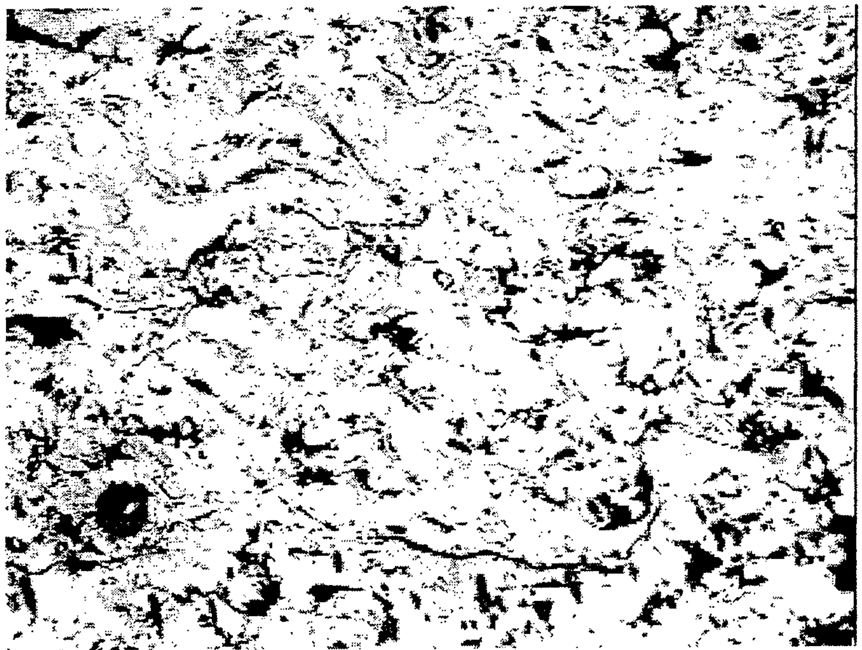


PHOTO 1 AS CAPTURED - BE1 200X

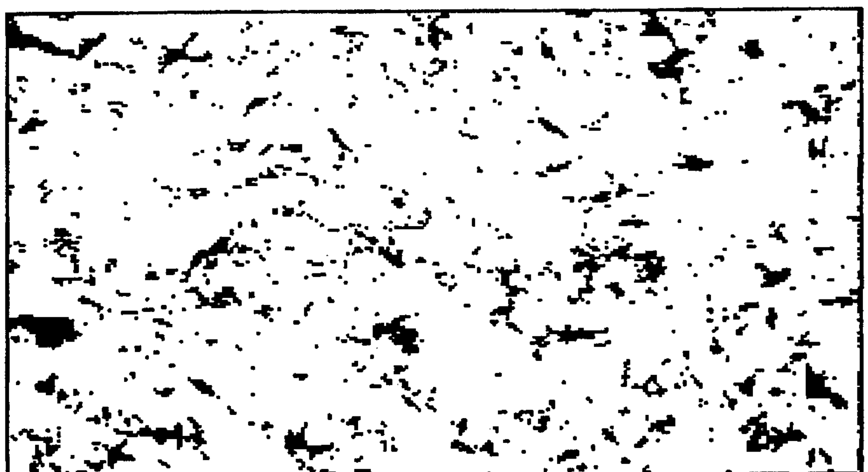


PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE1

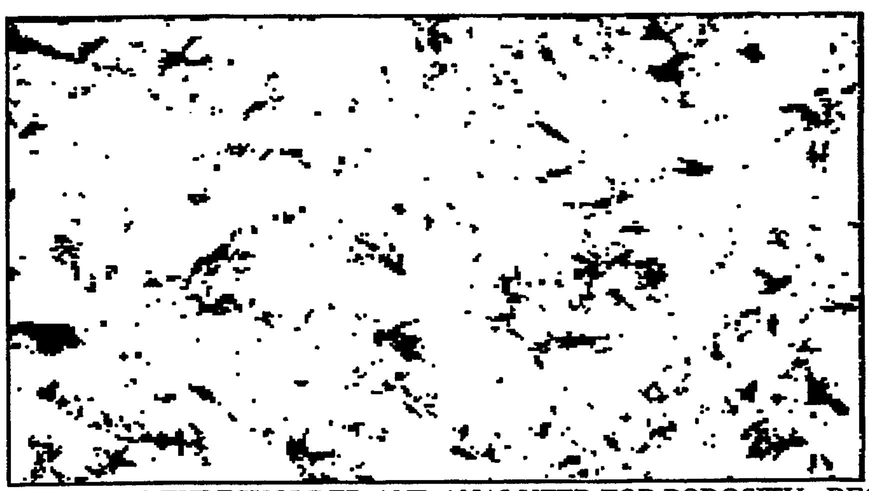


PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - BE1

Figure B1. Photomicrograph of Coating BE1 (3/16" 85/15)

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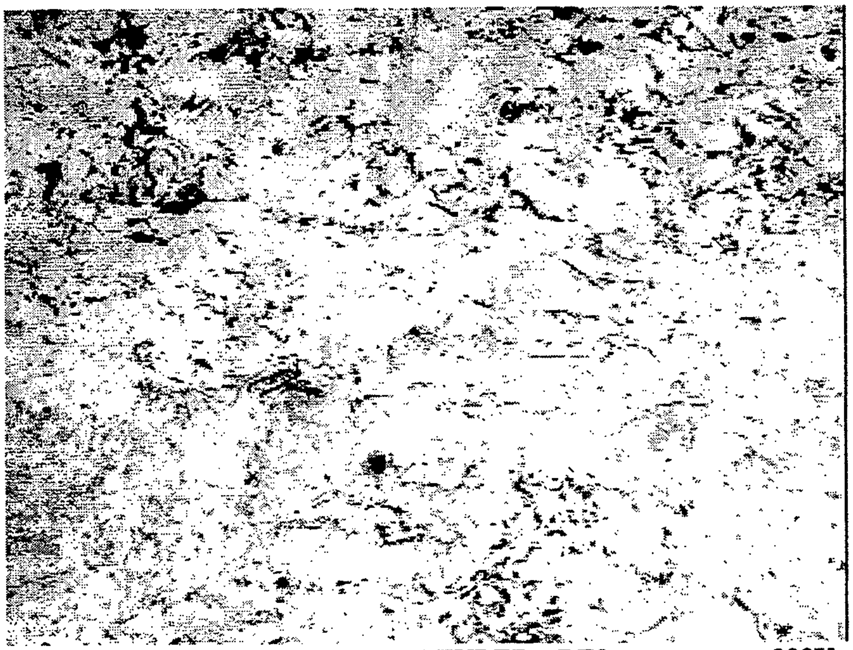

PHOTO 1 AS CAPTURED - BE2 200X

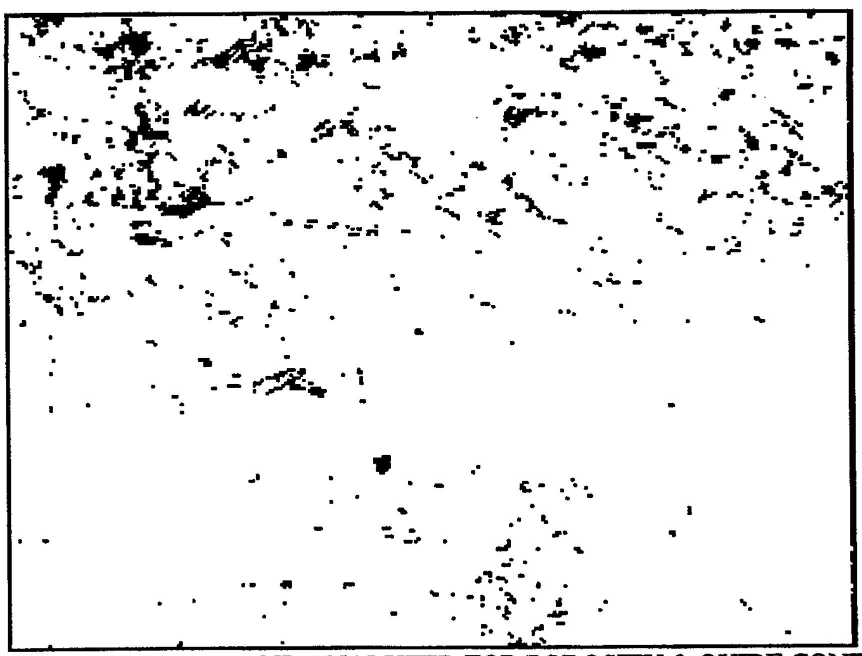

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE2

Figure B2. Photomicrograph of Coating BE2 (3/16" 85/15)

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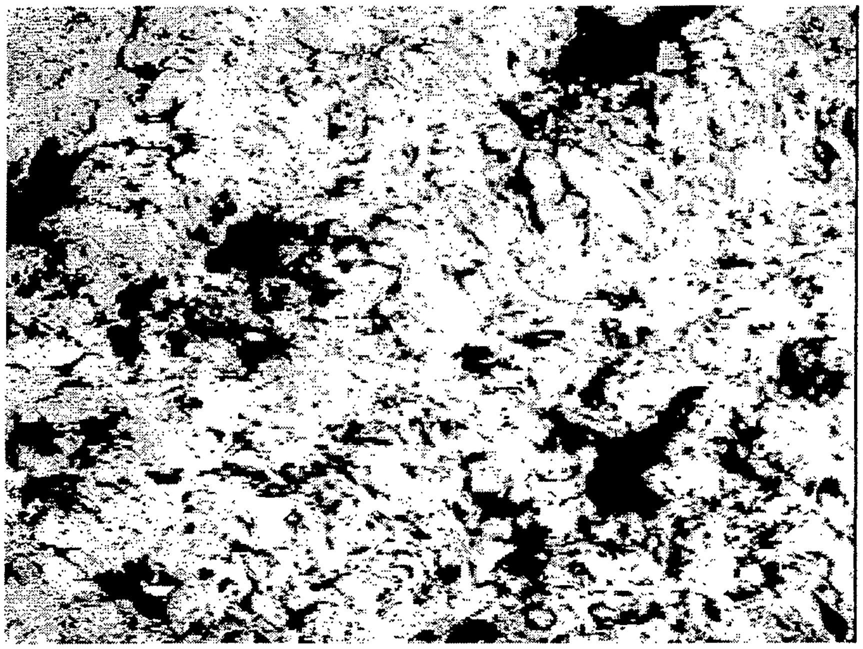

PHOTO 1 AS CAPTURED - BE3 200X

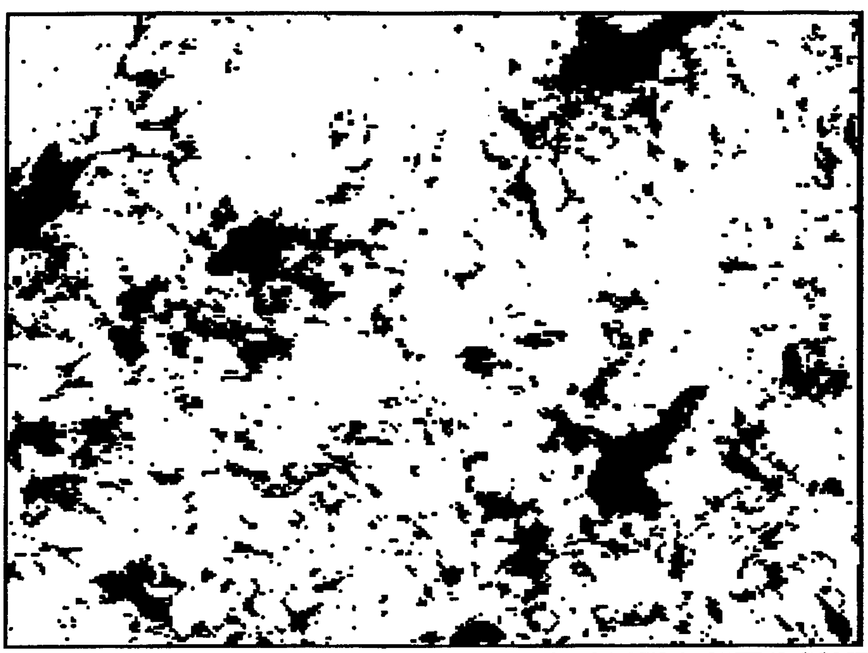

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE3

Figure B3. Photomicrograph of Coating BE3 (3/16" 85/15)

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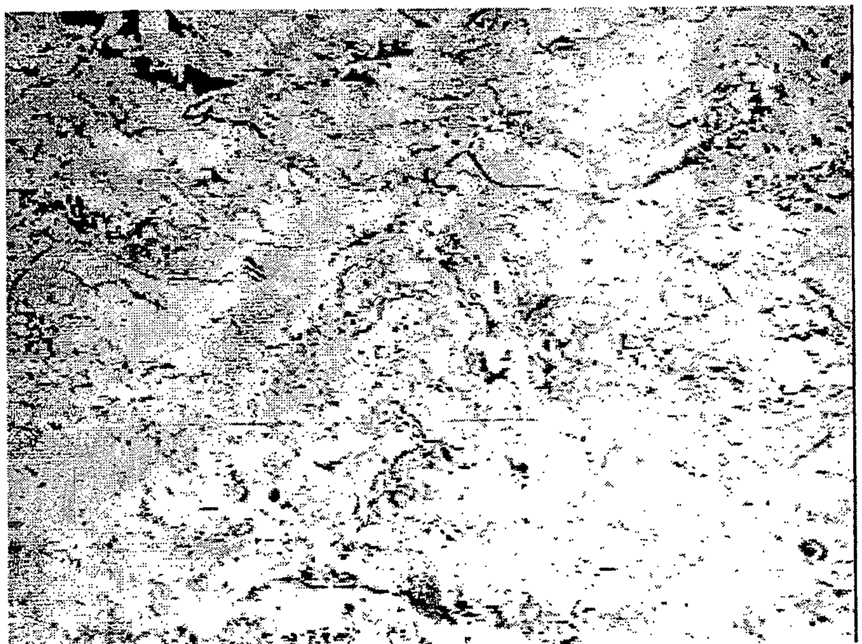

PHOTO 1 AS CAPTURED - BE4 200X

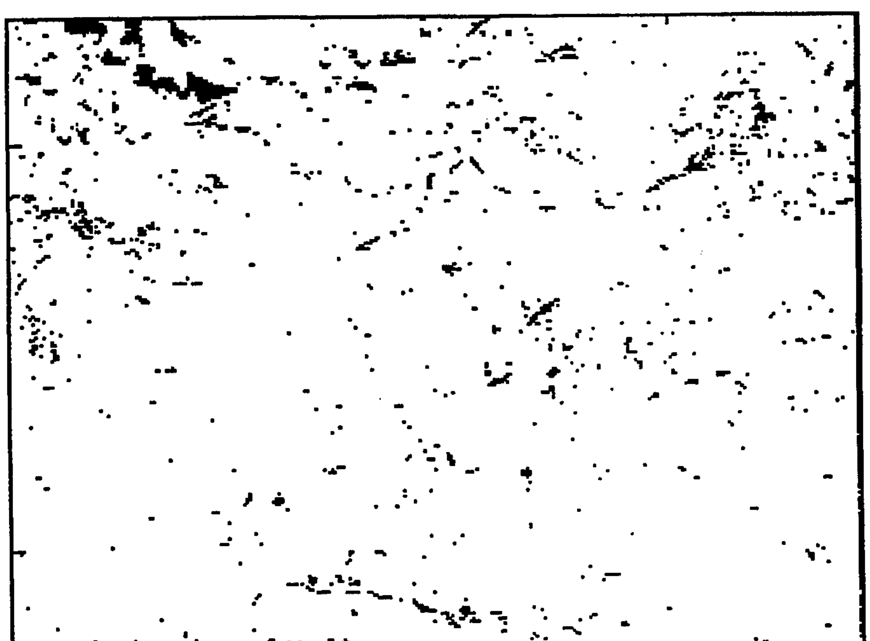

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE4

Figure B4. Photomicrograph of Coating BE4 (3/16" 85/15)

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PHOTO 1 AS CAPTURED - BE5 200X

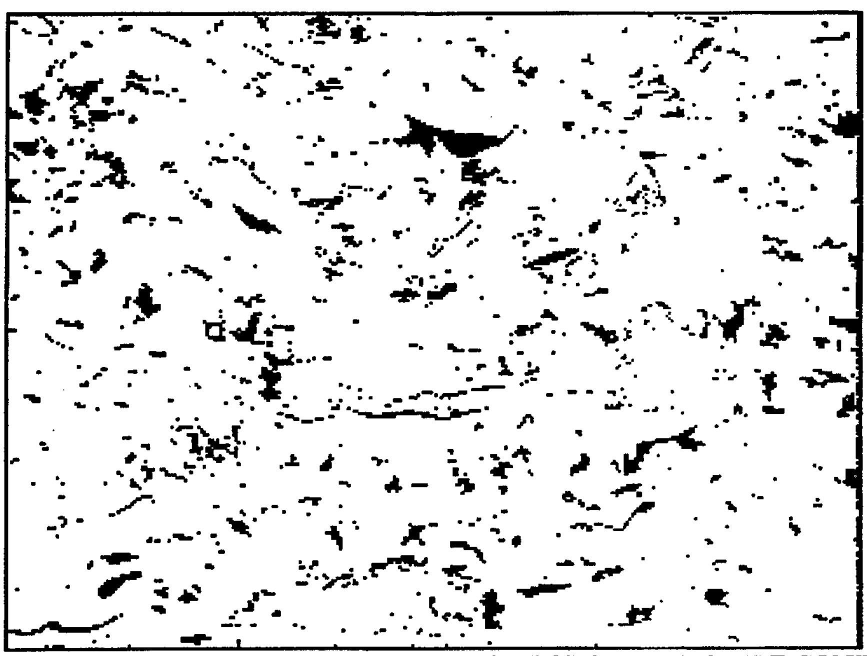

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE5

Figure B5. Photomicrograph of Coating BE5 (3/16" 85/15)

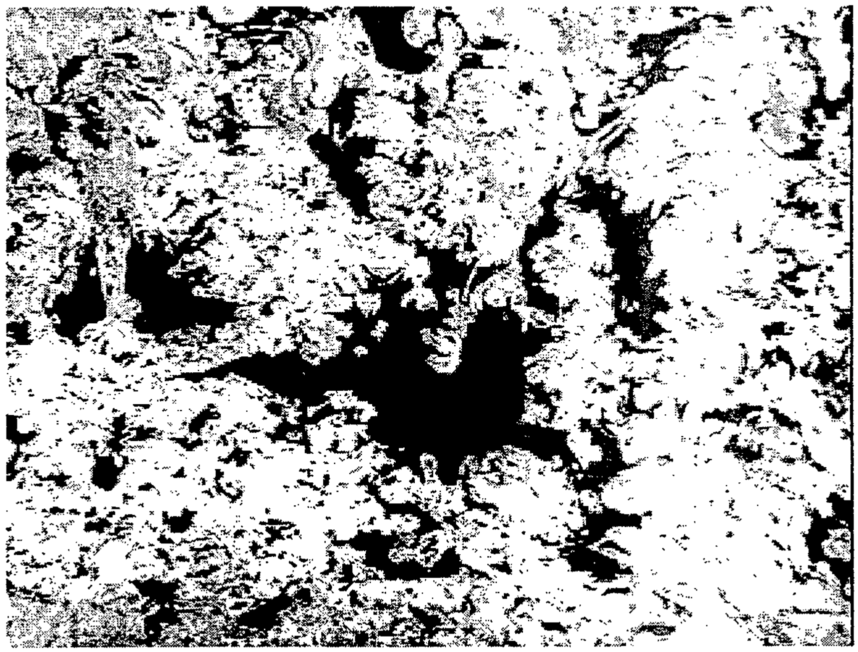

PHOTO 1 AS CAPTURED - BE6 200X

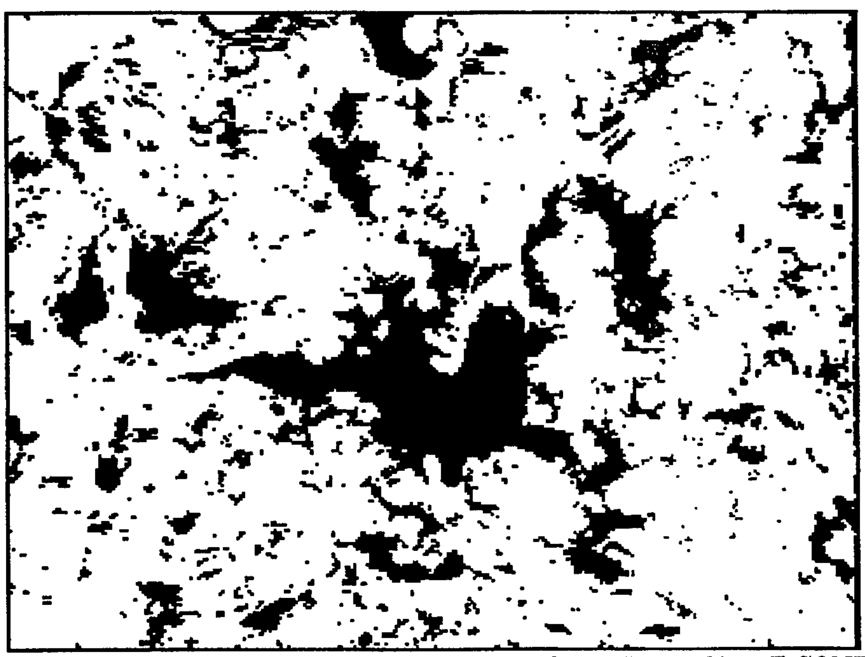

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE6

Figure B6. Photomicrograph of Coating BE6 (3/16" 85/15)

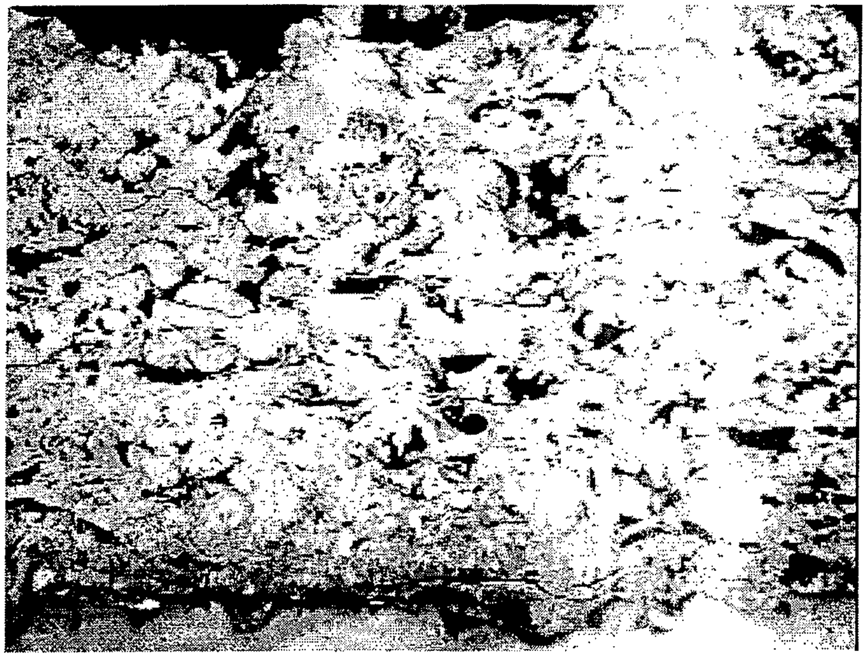

PHOTO 1 AS CAPTURED - BE7 200X

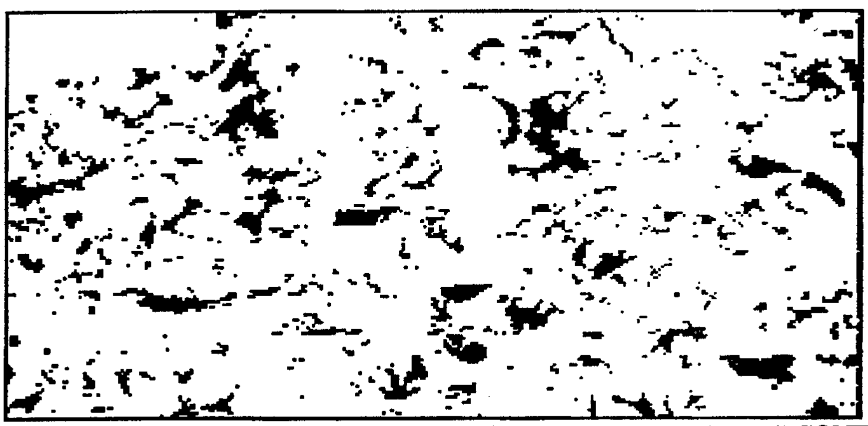

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE7

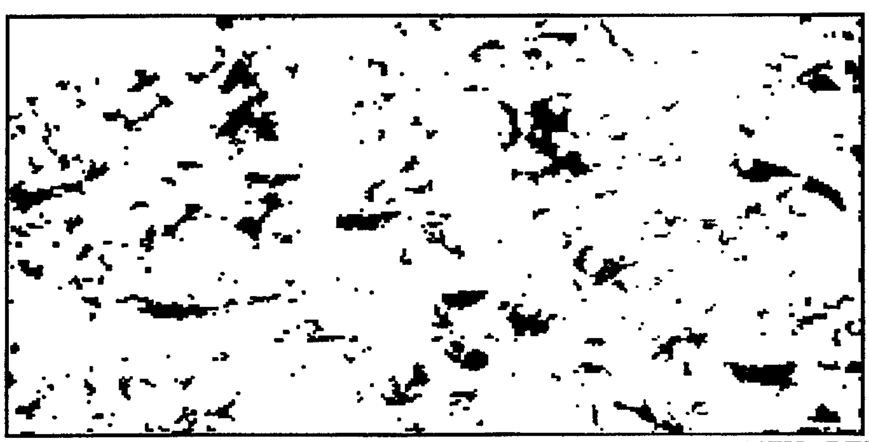

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY - BE7

Figure B7. Photomicrograph of Coating BE7 (3/16" 85/15)

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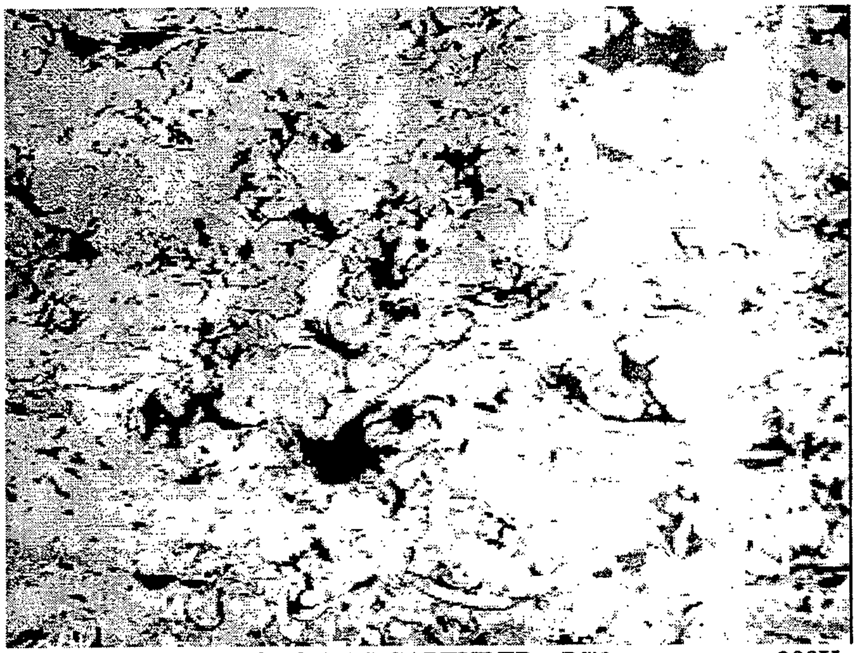

PHOTO 1 AS CAPTURED - BE8 200X

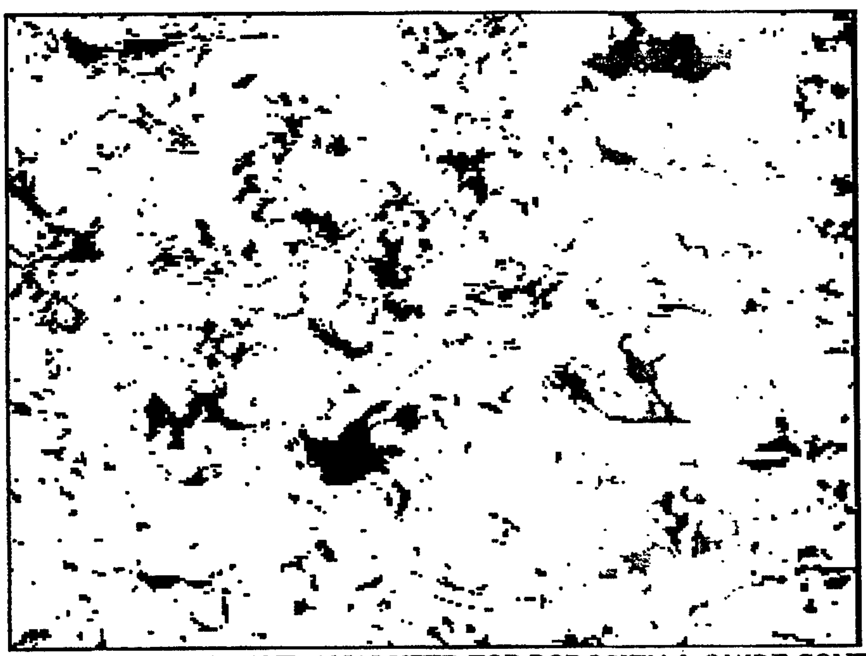

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE8

Figure B8. Photomicrograph of Coating BE8 (3/16" 85/15)

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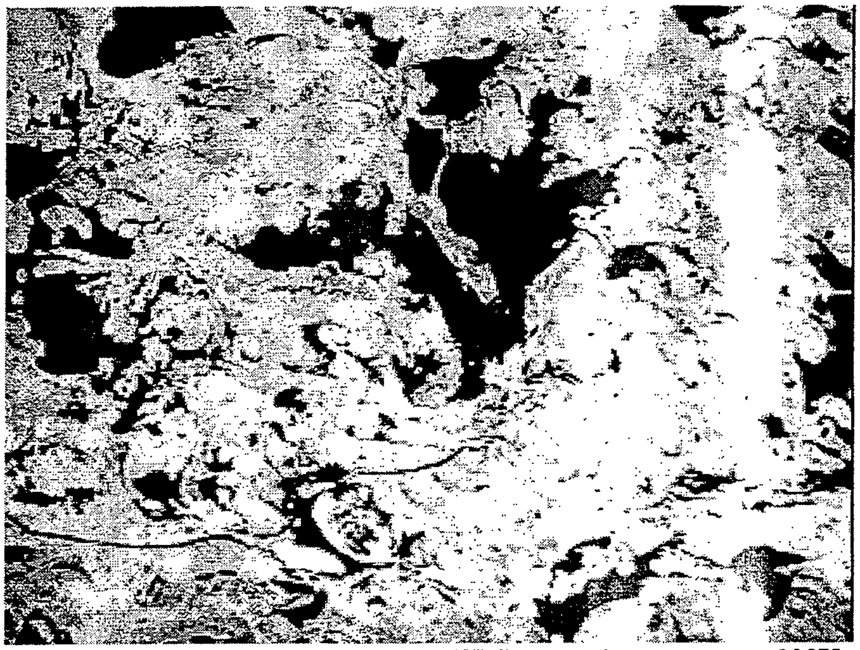

PHOTO 1 AS CAPTURED - BE9 200X

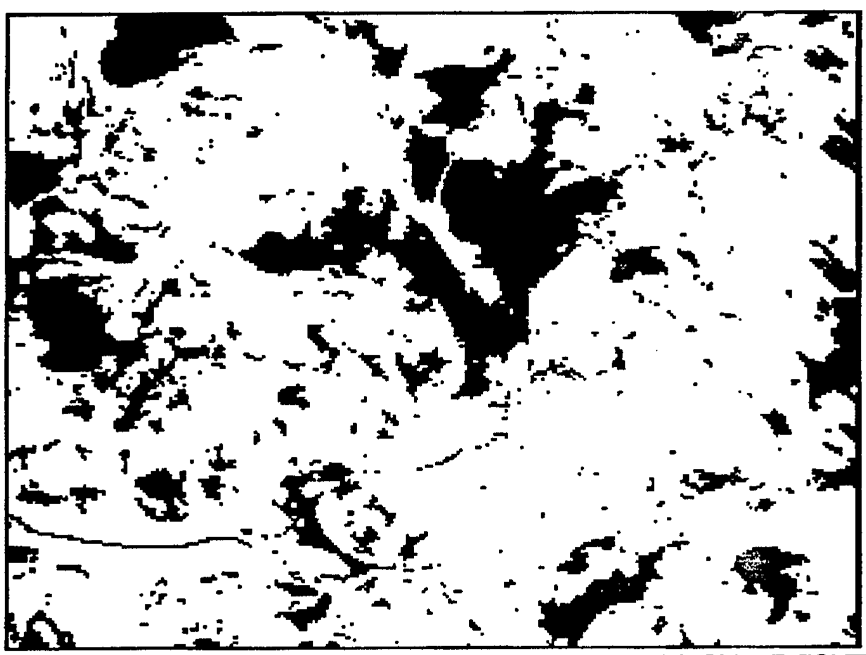

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE9

Figure B9. Photomicrograph of Coating BE9 (3/16" 85/15)

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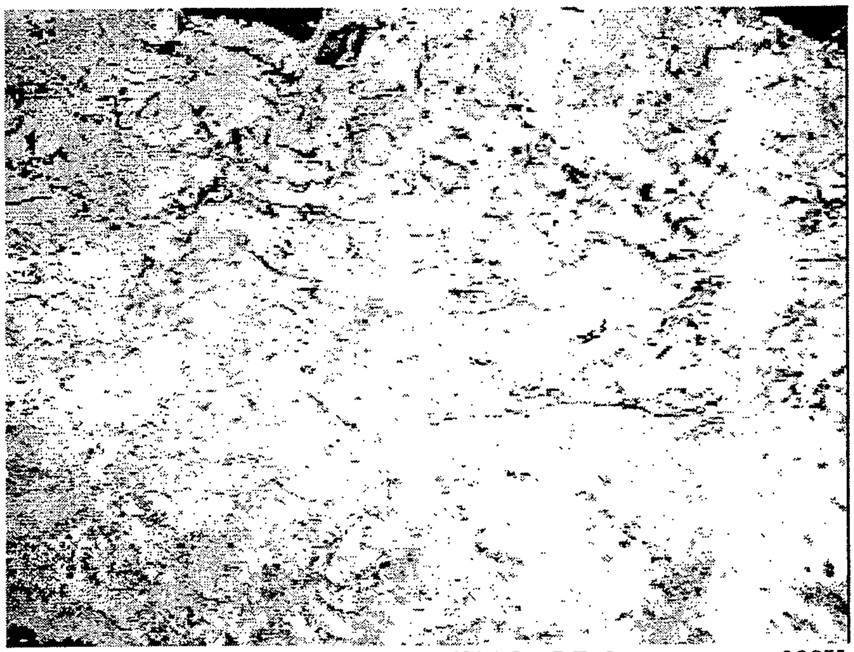

PHOTO 1 AS CAPTURED - BE10 200X

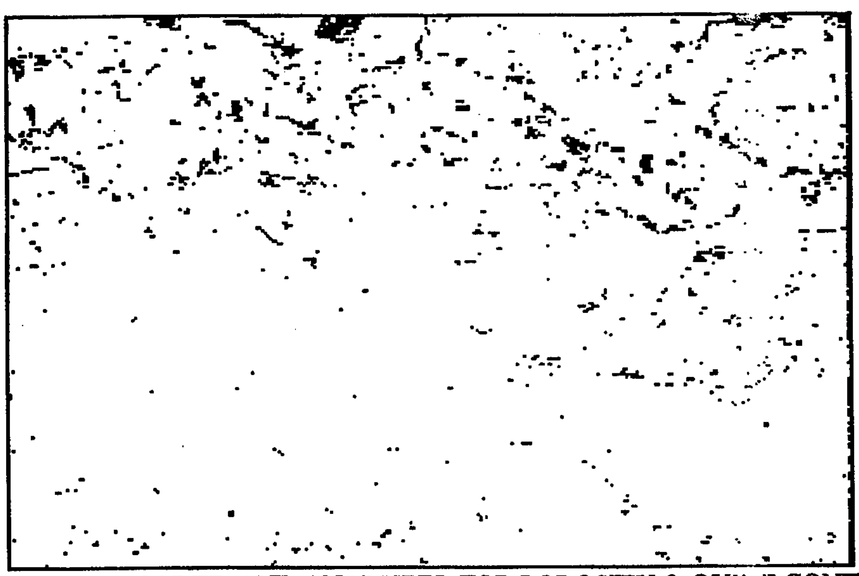

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE10

Figure B10. Photomicrograph of Coating BE10 (3/16" 85/15)

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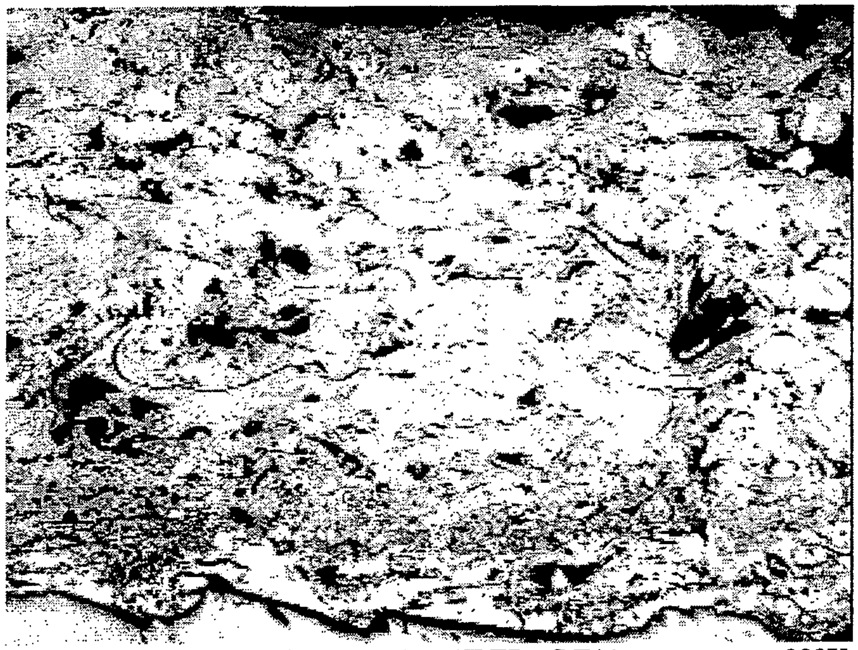

PHOTO 2 AS CAPTURED - BE11 200X

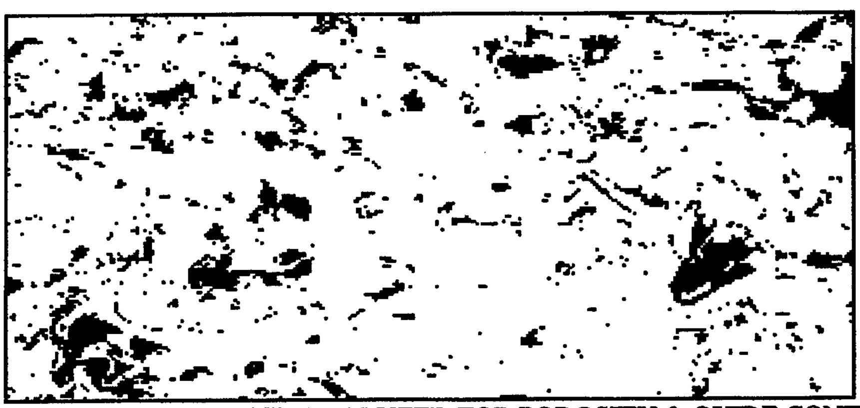

PHOTO 2 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE11

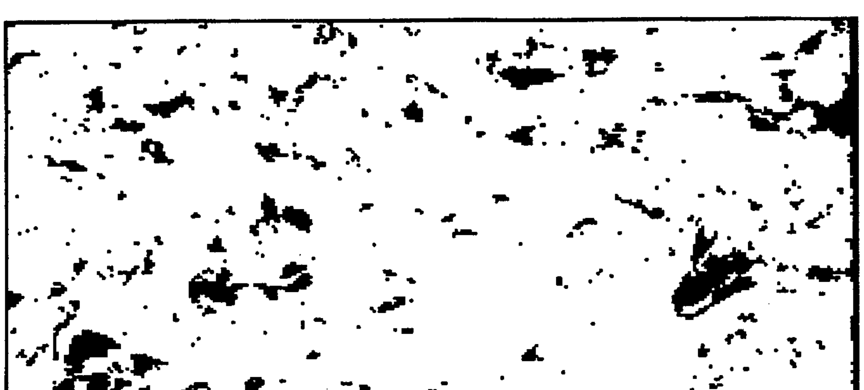

PHOTO 2 AS THRESHOLDED AND ANALYZED FOR POROSITY

Figure B11 Photomicrograph of Coating BE11 (3/15/85)

PROTECH LAB CORP.

Materials Testing Services

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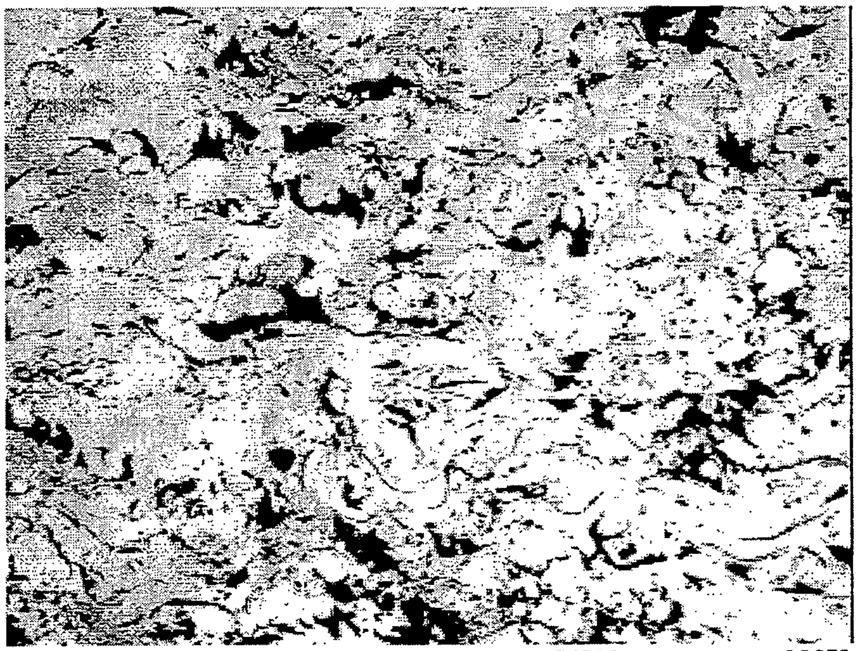

PHOTO 1 AS CAPTURED - BE12 200X

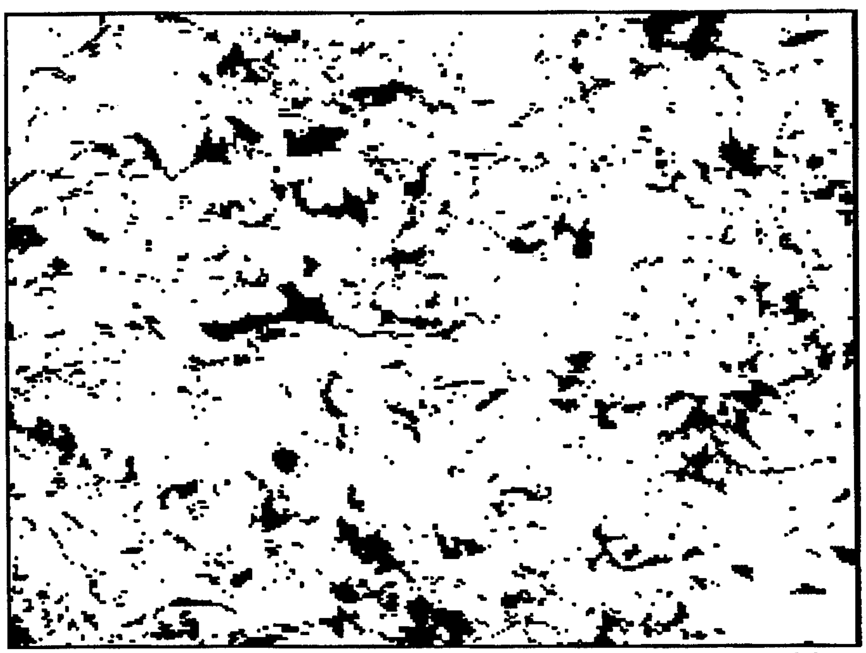

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE12

Figure B12. Photomicrograph of Coating BE12 (3/16" 85/15)

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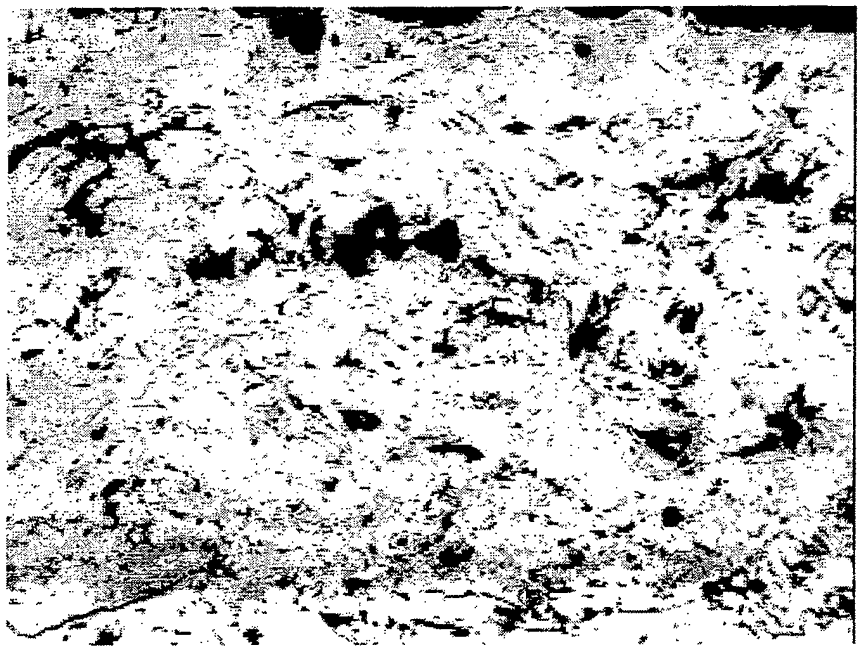

PHOTO 1 AS CAPTURED - BE13 200X

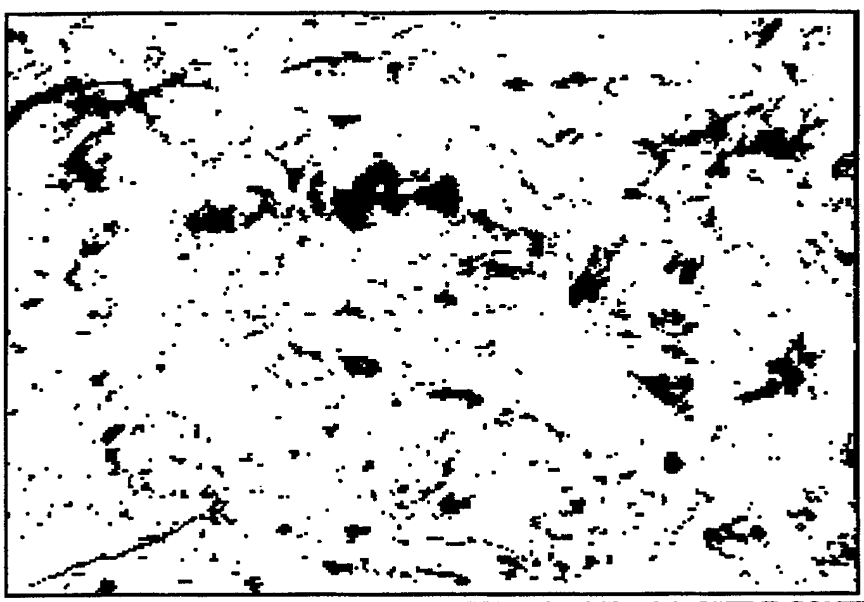

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE13

Figure B13. Photomicrograph of Coating BE13 (3/16" 85/15)

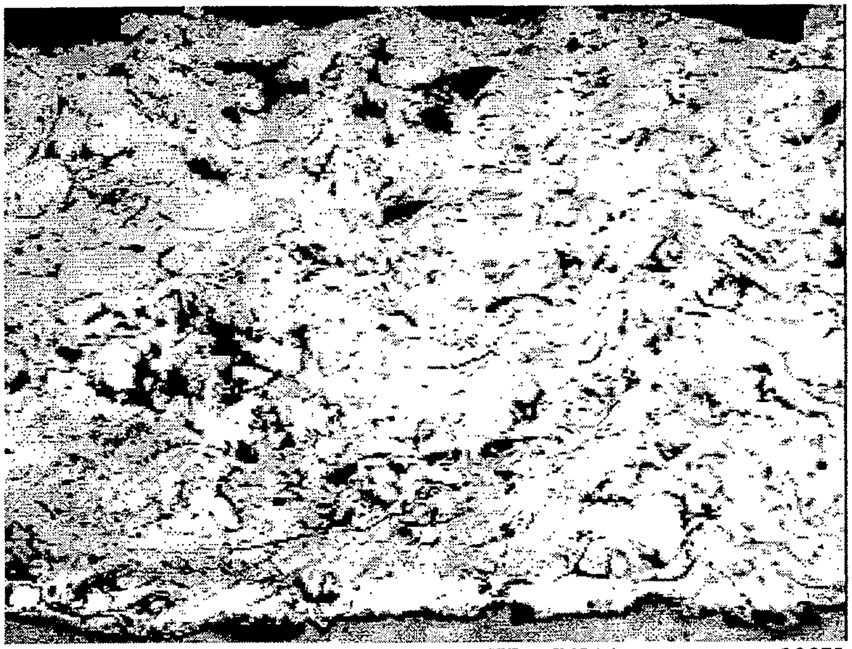

PHOTO 1 AS CAPTURED - BE14 200X

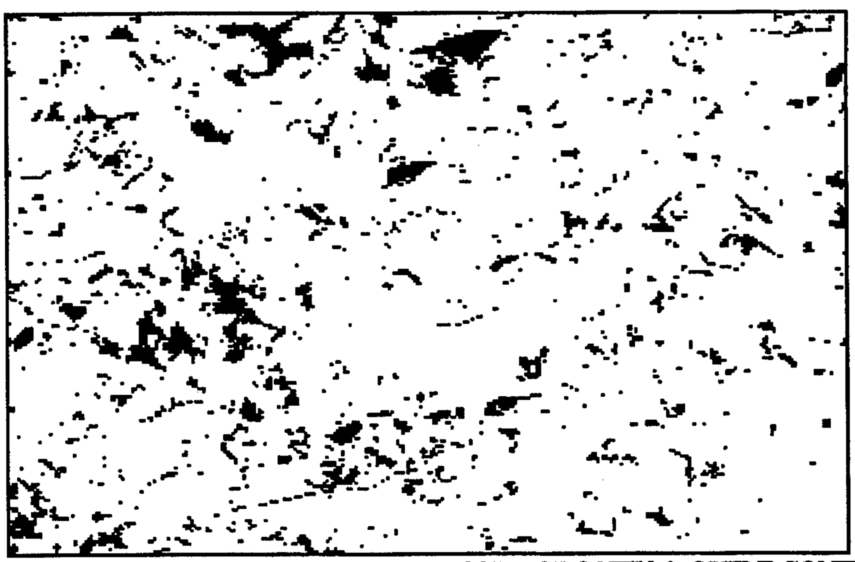

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE14

Figure B14. Photomicrograph of Coating BE14 (3/16" 85/15)

PROTECH LAB CORP.

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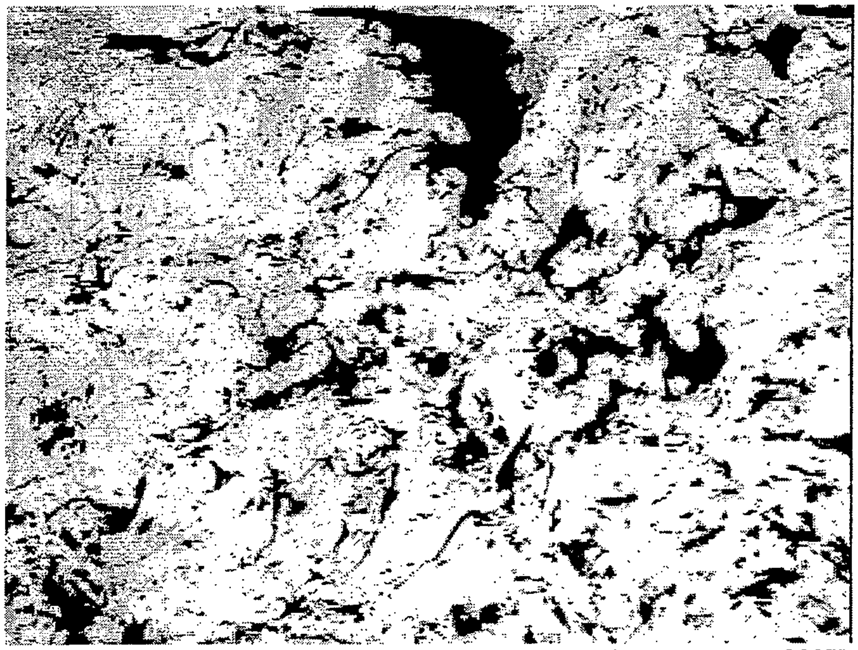

PHOTO 1 AS CAPTURED - BE15 200X

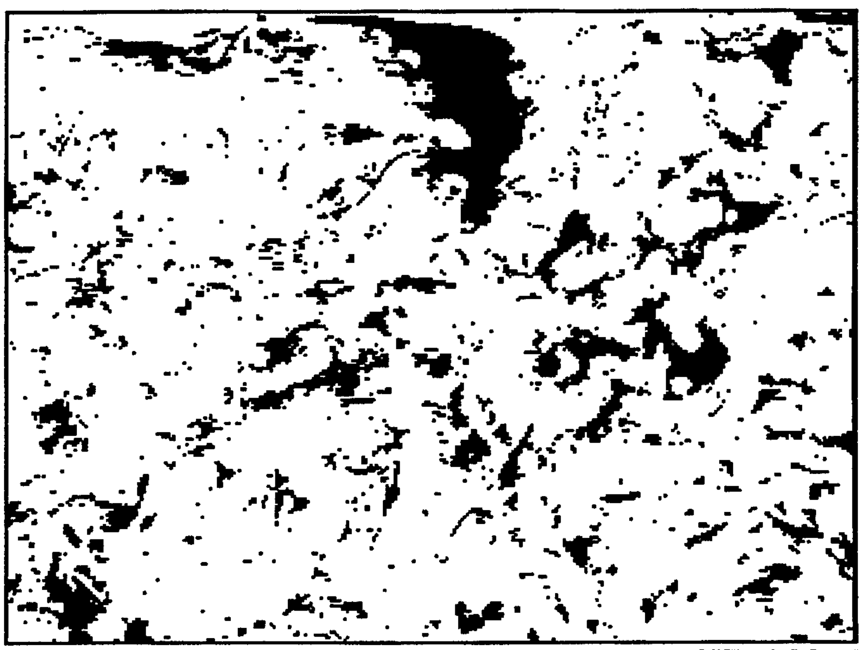

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE15

Figure B15. Photomicrograph of Coating BE15 (3/16" 85/15)

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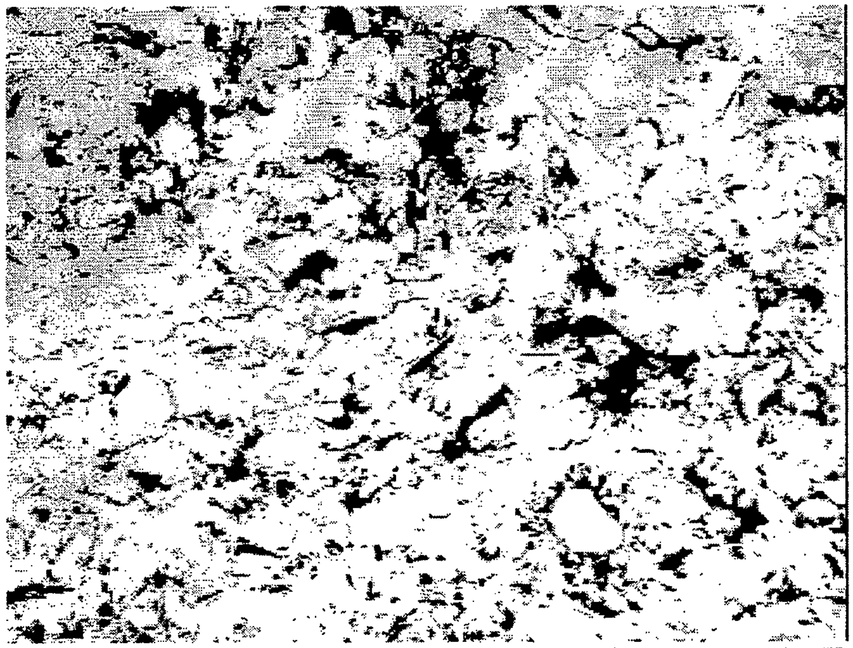

PHOTO 1 AS CAPTURED - BE16 200X

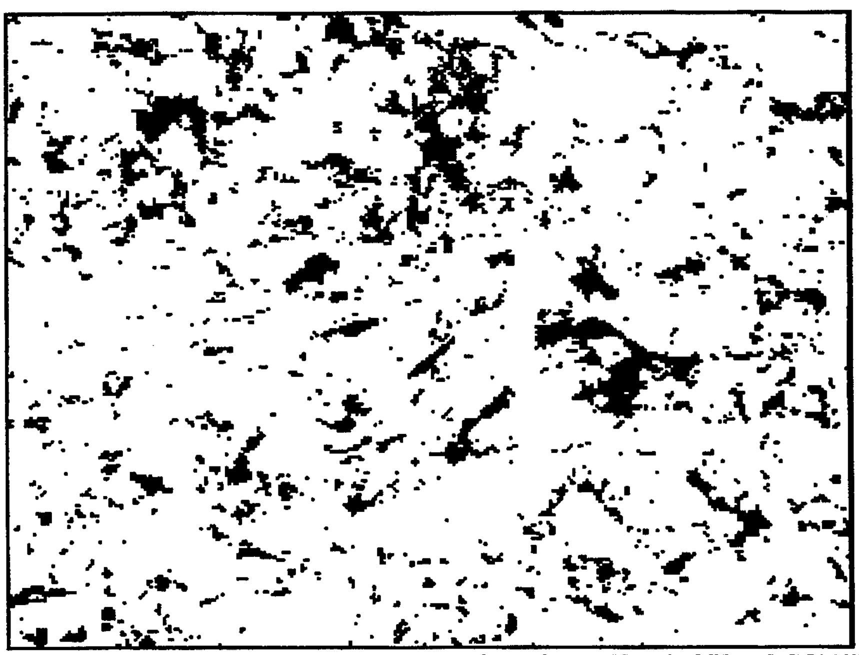

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE16

Figure B16. Photomicrograph of Coating BE16 (3/16" 85/15)

PROTECH LAB CORP.

Materials Testing Services

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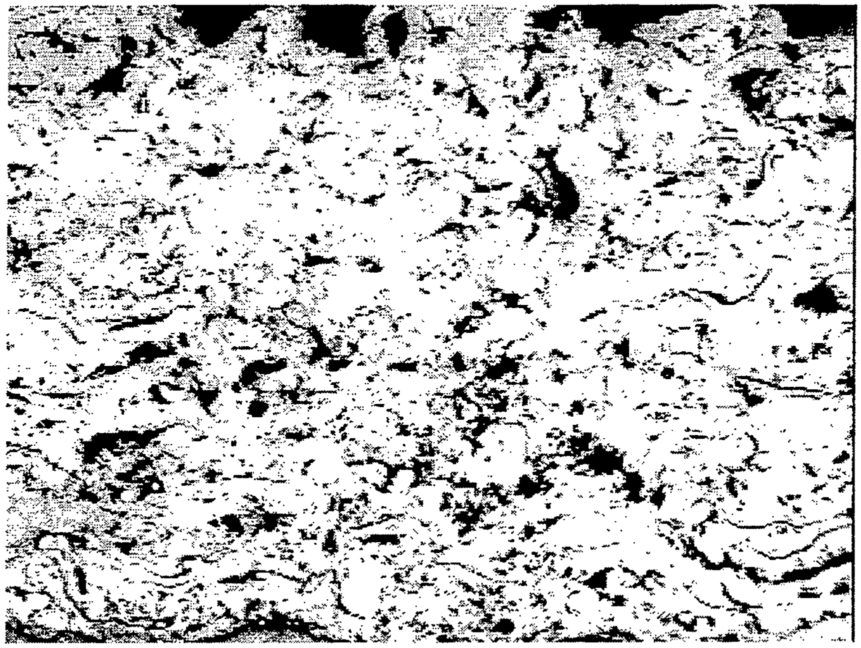

PHOTO 1 AS CAPTURED - BE17 200X

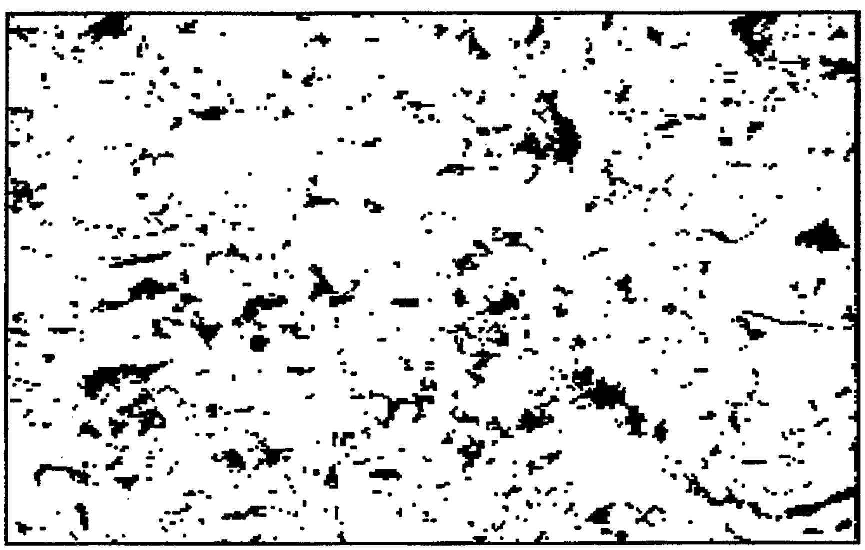

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE17

Figure B17. Photomicrograph of Coating BE17 (3/16" 85/15)

PROTECH LAB CORP.

Materials Testing Services

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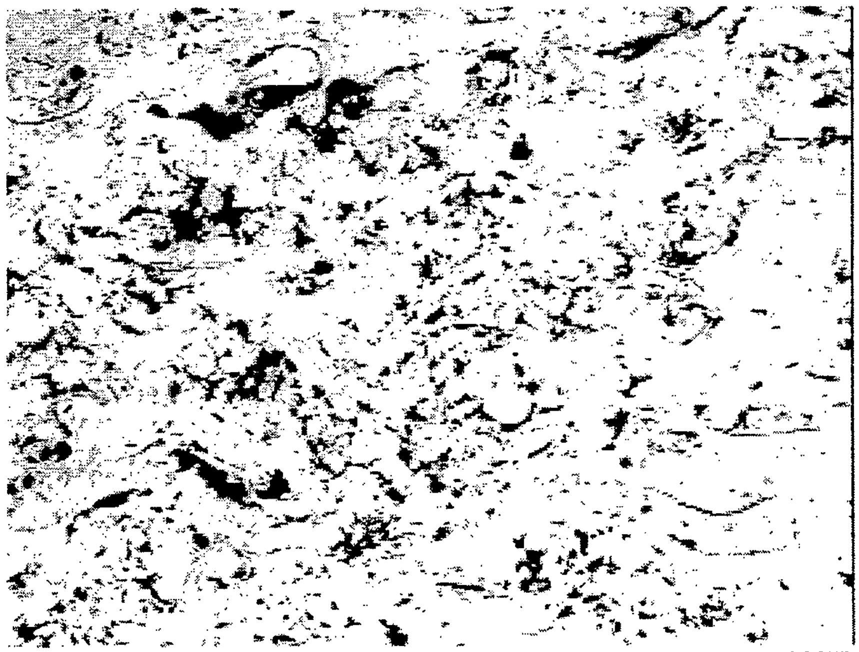

PHOTO 1 AS CAPTURED - BE18 200X

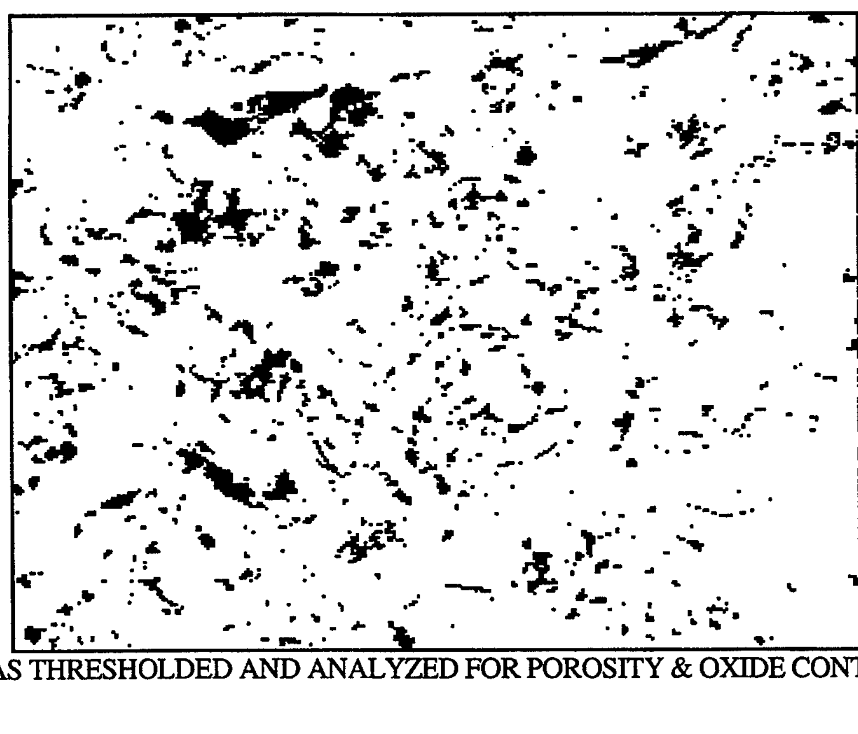

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE18

Figure B18. Photomicrograph of Coating BE18 (3/16" 85/15)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

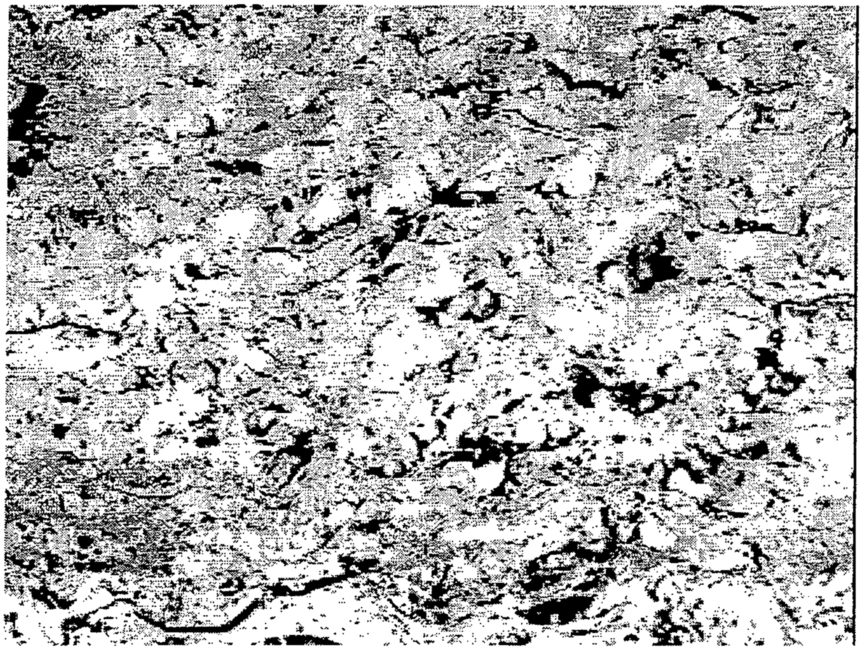

PHOTO 1 AS CAPTURED - BE19 200X

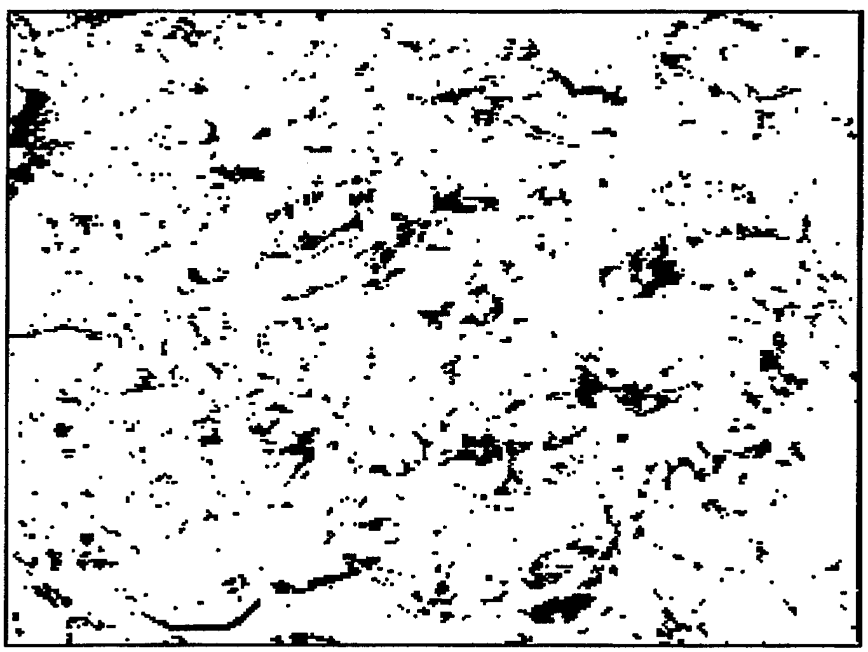

PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE19

Figure B19. Photomicrograph of Coating BE19 (3/16" 85/15)

PROTECH LAB CORP.

Materials Testing Services

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PHOTO 1 AS CAPTURED - BE20 200X

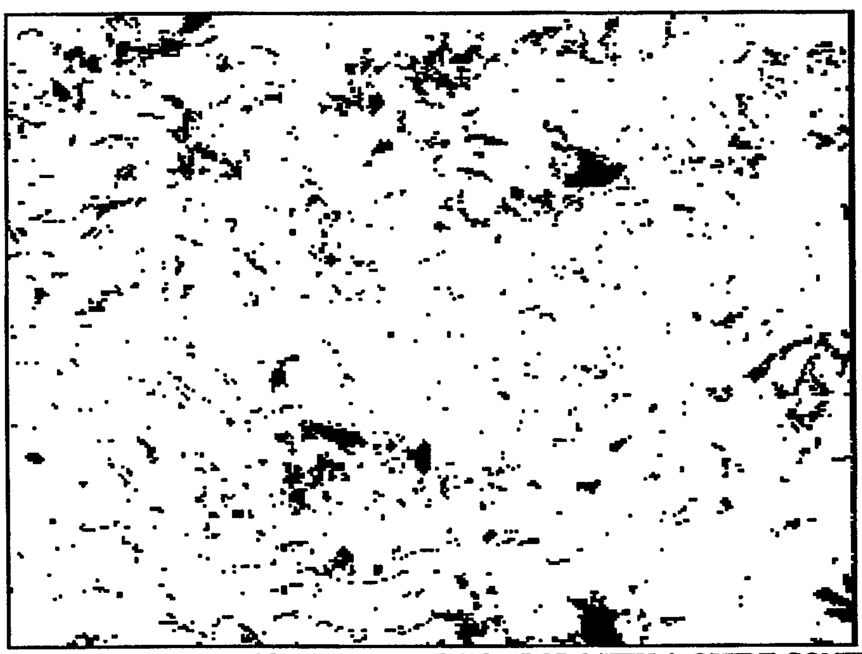


PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE20

Figure B20. Photomicrograph of Coating BE20 (3/16" 85/15)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

PHOTO 1 AS CAPTURED - BE21 200X

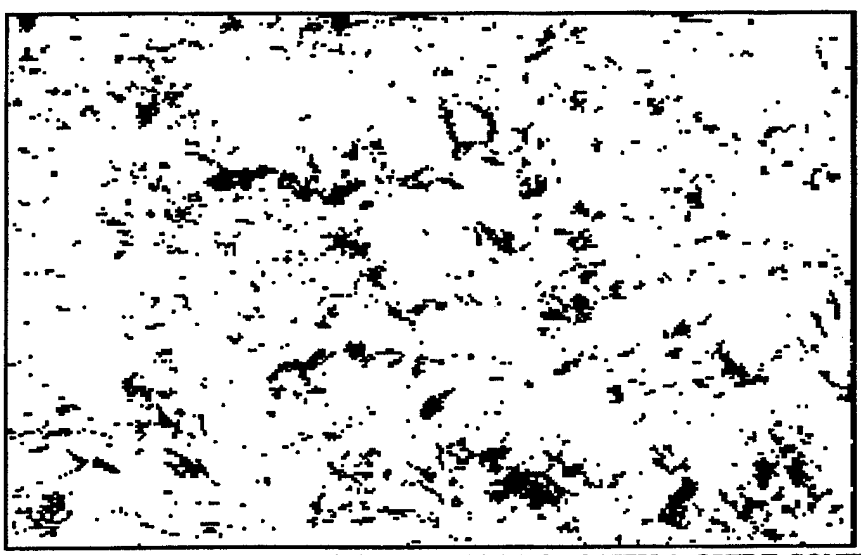
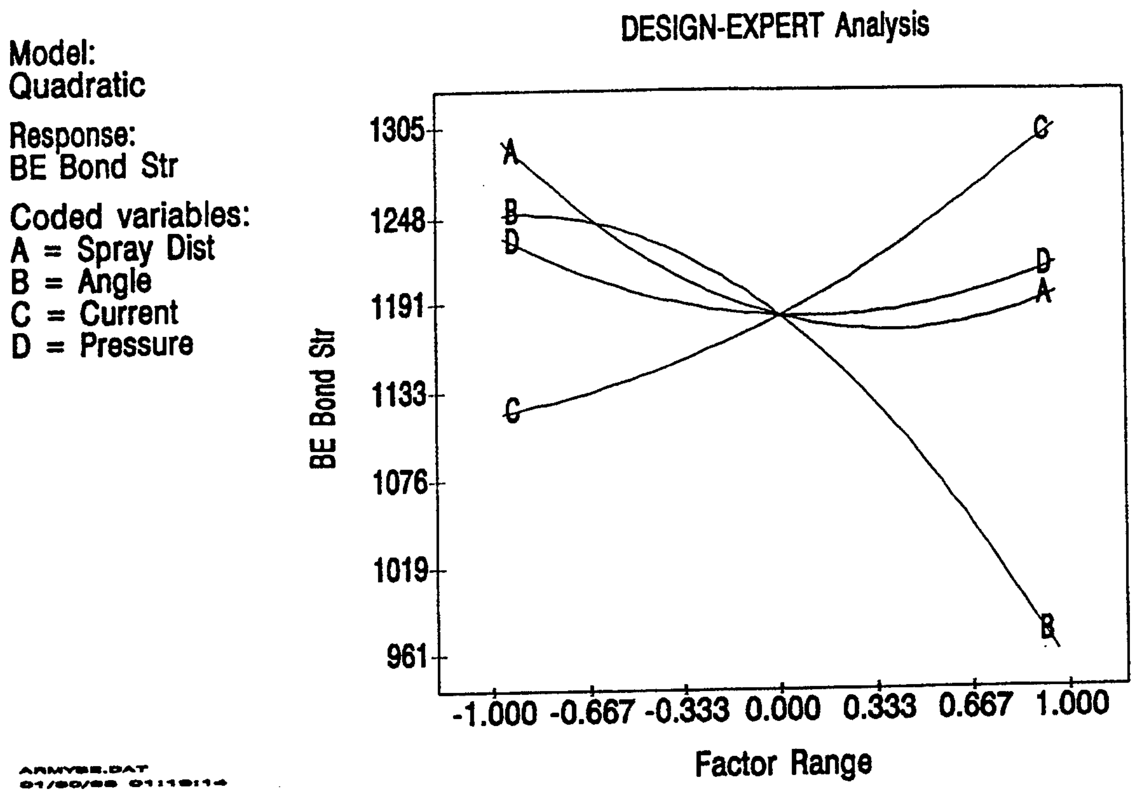


PHOTO 1 AS THRESHOLDED AND ANALYZED FOR POROSITY & OXIDE CONTENT - BE21

Figure B21. Photomicrograph of Coating BE21 (3/16" 85/15)



Figures B22. Response Surface Plot of Bond Strength (BE coatings)

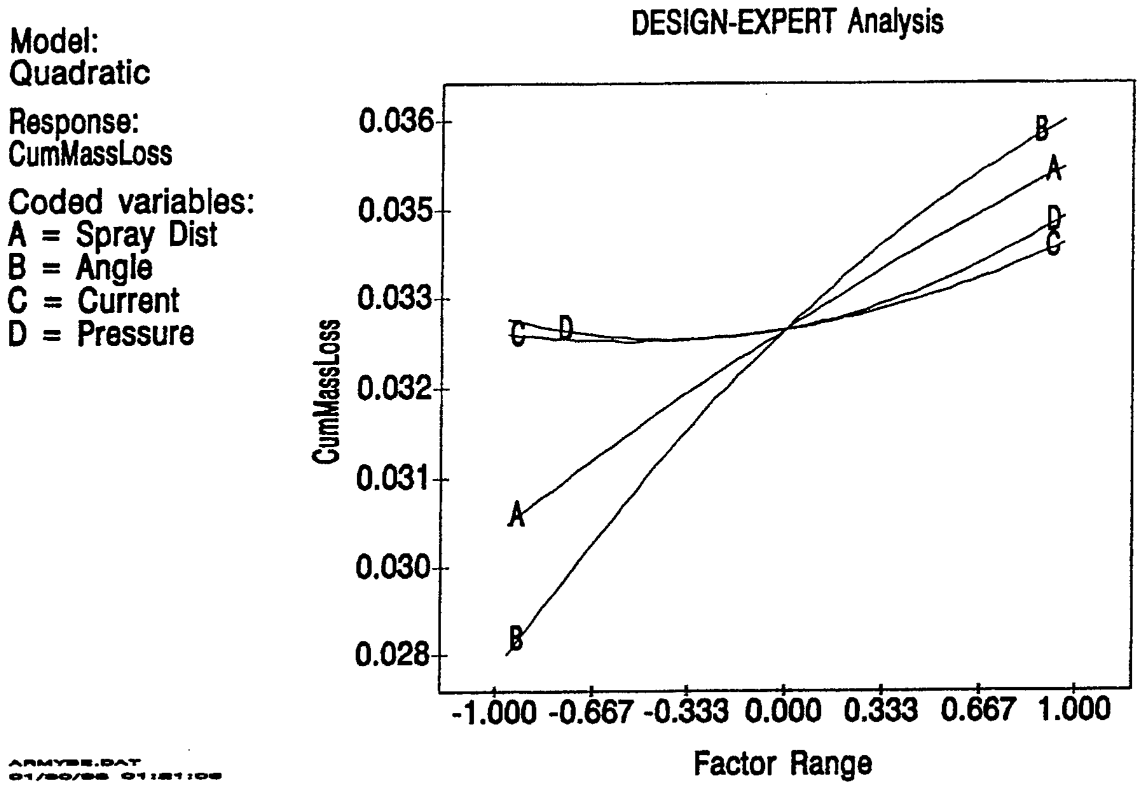


Figure B23. Response Surface Plot of CML (BE coatings)

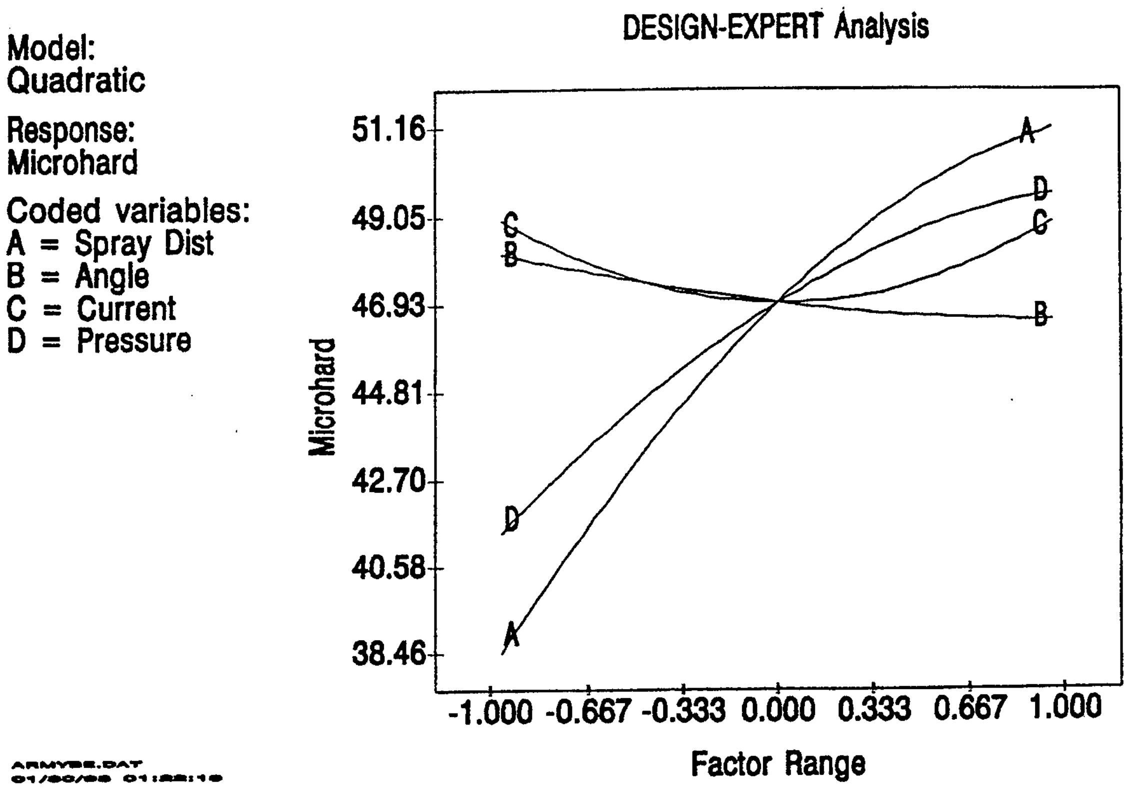


Figure B24. Response Surface Plot of Microhardness (BE coatings)

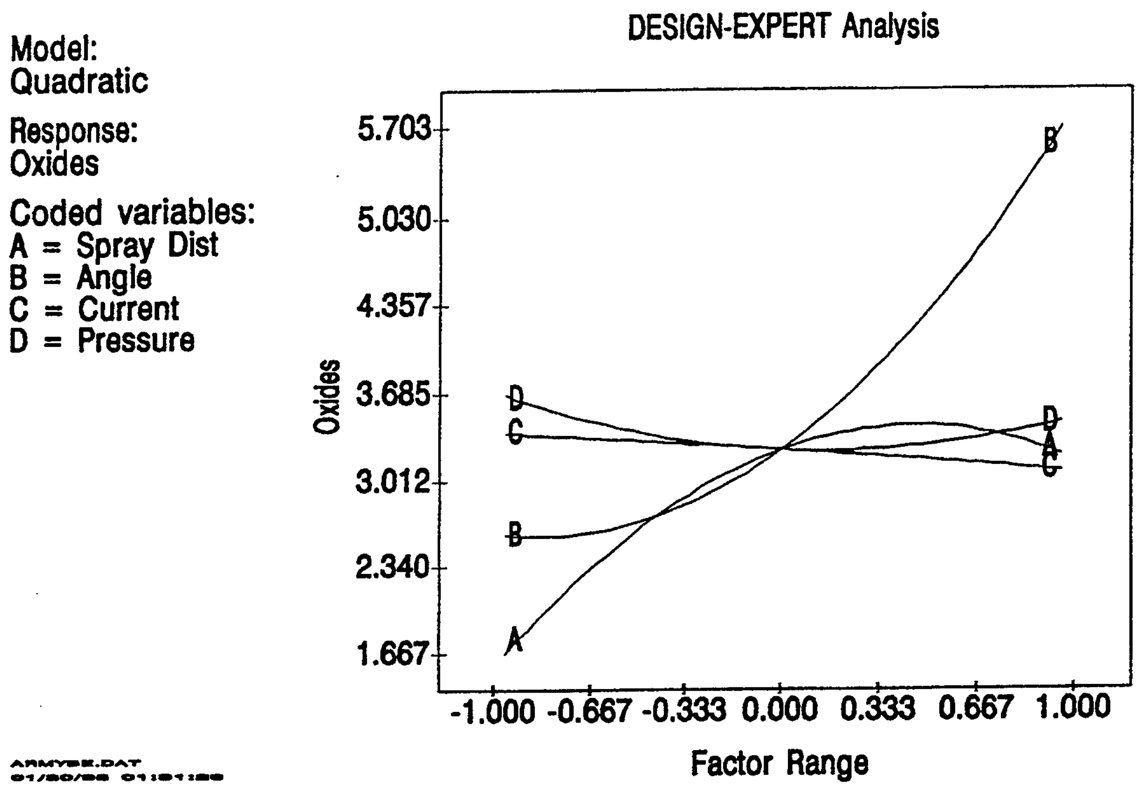


Figure B25. Response Surface Plot of Oxide Content (BE coatings)

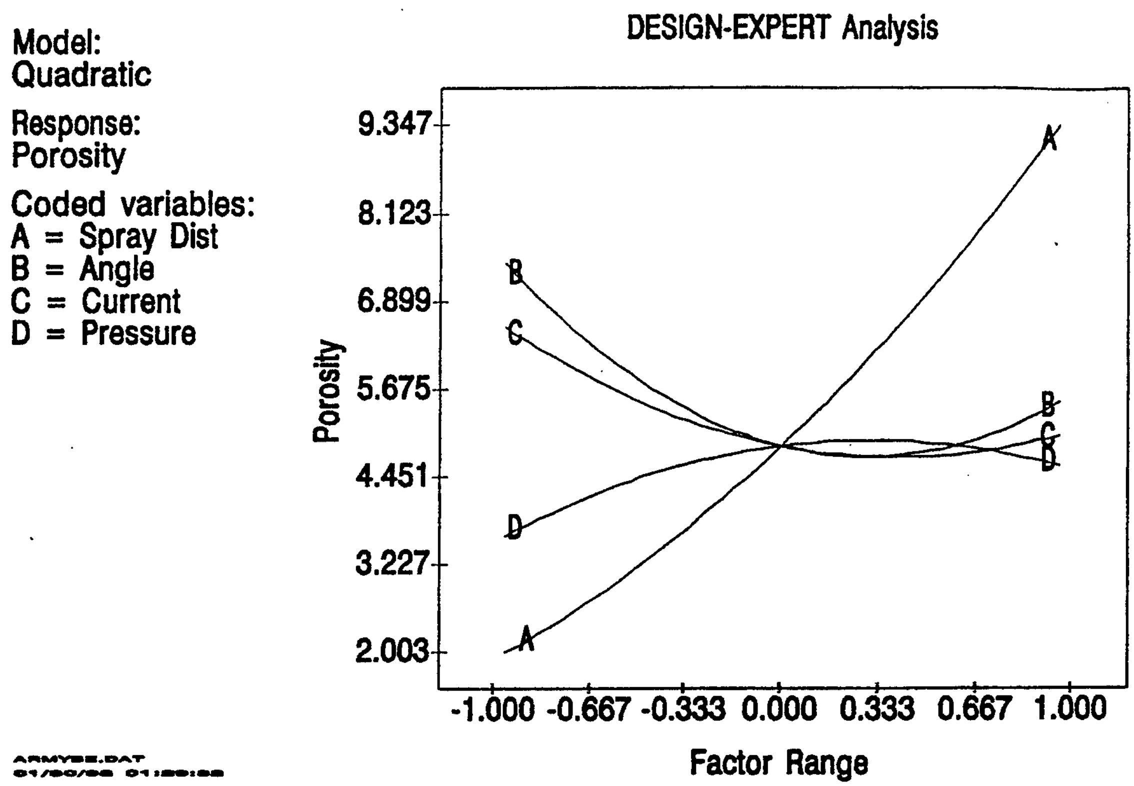


Figure B26. Response Surface Plot of Porosity (BE coatings)

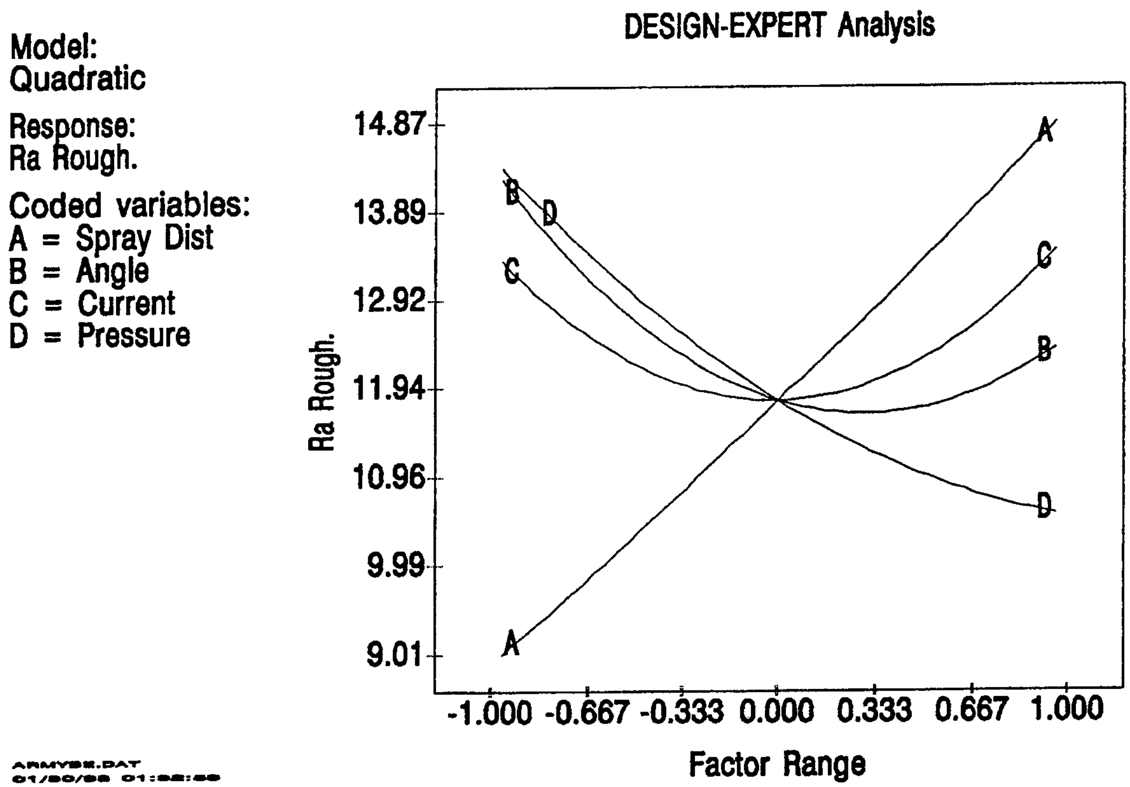


Figure B27. Response Surface Plot of Roughness (BE coatings)

Table B1. 3/16" 85/15 Statistical Analysis of Bond Strength

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	32530608.0	1	32530608.0		
Linear	68927.5	4	17231.9	1.865	0.1659
Quadratic	108281.1	10	10828.1	1.643	0.2808
Cubic	7825.2	2	3912.6	0.4933	0.6434
RESIDUAL	31723.2	4	7930.8		
TOTAL	32747365.0	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	116106.2	12	9675.5	1.220	0.4630
Quadratic	7825.2	2	3912.6	0.4933	0.6434
Cubic	0.0	0			
PURE ERR	31723.2	4	7930.8		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	96.1	0.3180	0.1475	266910.0
Quadratic	15	6	81.2	0.8175	0.3918	1675807.5
Cubic	17	4	89.1	0.8536	0.2682	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	177208.5	14	12657.8	1.920	0.2166
RESIDUAL	39548.4	6	6591.4		
Lack Of Fit	7825.2	2	3912.6	0.4933	0.6434
Pure Error	31723.3	4	7930.8		
COR TOTAL	216757.0	20			
ROOT MSE	81.2		R-SQUARED	0.8175	
DEP MEAN	1244.6		ADJ R-SQUARED	0.3918	
C.V.	6.52%				

Predicted Residual Sum of Squares (PRESS) = 1675807.5

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	1183.6	1	30.5	38.83	
A	-52.8	1	48.1	-1.098	0.3143
B	-150.5	1	150.7	-0.999	0.3565
C	97.0	1	57.4	1.690	0.1421
D	-10.5	1	57.4	-0.1829	0.8609
A2	68.7	1	48.2	1.424	0.2042
B2	-84.3	1	82.3	-1.024	0.3454
C2	30.9	1	46.8	0.6604	0.5335
D2	45.7	1	44.3	1.031	0.3422
AB	19.2	1	110.0	0.1745	0.8672
AC	33.0	1	115.5	0.2856	0.7848

AD	-108.1	1	124.9	-0.8656	0.4200
BC	159.7	1	53.9	2.961	0.0253
BD	-78.6	1	83.7	-0.9390	0.3840
CD	-60.4	1	123.7	-0.4886	0.6425

Final Equation in Terms of Actual Factors:

```
     BE Bond Str =
                          239.3
              +          141.28 * Spray Dist
              +          30.793 * Angle
              -          2.5233 * Current
              -          7.4540 * Pressure
              +          7.6309 * Spray Dist^2
              -         0.16646 * Angle      ^2
              +       3.088E-03 * Current^2
              +         0.45708 * Pressure^2
              +         0.28454 * Spray Dist * Angle
              +         0.10999 * Spray Dist * Current
              -          3.6035 * Spray Dist * Pressure
              +       7.096E-02 * Angle       * Current
              -         0.34916 * Angle       * Pressure
              -       6.045E-02 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	1335.0	1326.1	8.9
2	1294.0	1305.0	-11.0
3	1315.0	1322.9	-7.9
4	1406.0	1363.5	42.5
5	1437.0	1428.1	8.9
6	1376.0	1400.6	-24.6
7	1223.0	1247.6	-24.6
8	1080.0	1087.9	-7.9
9	1141.0	1132.1	8.9
10	1315.0	1305.0	10.0
11	1162.0	1183.6	-21.6
12	1223.0	1199.4	23.6
13	1223.0	1249.8	-26.8
14	1049.0	1183.6	-134.6
15	1171.0	1147.4	23.6
16	1141.0	1117.4	23.6
17	1212.0	1183.6	28.4
18	1335.0	1311.4	23.6
19	1213.0	1239.8	-26.8
20	1294.0	1183.6	110.4
21	1192.0	1218.8	-26.8

□

Table B2. 3/16" 85/15 Statistical Analysis of Cumulative Mass Loss

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	0.0192860	1	0.0192860		
Linear	0.0005672	4	0.0001418	15.62	0.0001
Quadratic	0.0001016	10	0.0000102	1.395	0.3546
Cubic	0.0000046	2	0.0000023	0.2358	0.8002
RESIDUAL	0.0000391	4	0.0000098		
TOTAL	0.0199984	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	0.0001062	12	0.0000088	0.9056	0.6012
Quadratic	0.0000046	2	0.0000023	0.2358	0.8002
Cubic	0.0000000	0			
PURE ERR	0.0000391	4	0.0000098		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	0.00301	0.7961	0.7451	0.00029
Quadratic	15	6	0.00270	0.9387	0.7956	0.00090
Cubic	17	4	0.00313	0.9451	0.7257	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	0.0006687	14	0.00005	6.560	0.0146
RESIDUAL	0.0000437	6	0.00001		
Lack Of Fit	0.0000046	2	0.00000	0.2358	0.8002
Pure Error	0.0000391	4	0.00001		
COR TOTAL	0.0007124	20			
ROOT MSE	0.00270		R-SQUARED	0.9387	
DEP MEAN	0.03030		ADJ R-SQUARED	0.7956	
C.V.	8.90%				

Predicted Residual Sum of Squares (PRESS) = 0.0008967

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	0.03291	1	0.00101	32.48	
A	0.00260	1	0.00160	1.628	0.1546
B	0.00391	1	0.00501	0.7803	0.4649
C	0.00065	1	0.00191	0.3407	0.7450
D	0.00075	1	0.00191	0.3931	0.7079
A2	-0.00024	1	0.00160	-0.1524	0.8838
B2	-0.00091	1	0.00274	-0.3316	0.7515
C2	0.00061	1	0.00155	0.3913	0.7091
D2	0.00094	1	0.00147	0.6353	0.5487
AB	-0.00251	1	0.00366	-0.6854	0.5187

AC	-0.00284	1	0.00384	-0.7407	0.4869
AD	0.00437	1	0.00415	1.054	0.3326
BC	0.00032	1	0.00179	0.1764	0.8658
BD	0.00343	1	0.00278	1.232	0.2639
CD	0.00505	1	0.00411	1.228	0.2656

Final Equation in Terms of Actual Factors:

CumMassLoss =

```
                 0.47347
      -       6.562E-03 * Spray Dist
      -       7.420E-04 * Angle
      -       4.681E-04 * Current
      -       6.247E-03 * Pressure
      -       2.714E-05 * Spray Dist^2
      -       1.791E-06 * Angle      ^2
      +       6.081E-08 * Current^2
      +       9.360E-06 * Pressure^2
      -       3.714E-05 * Spray Dist * Angle
      -       9.481E-06 * Spray Dist * Current
      +       1.458E-04 * Spray Dist * Pressure
      +       1.405E-07 * Angle       * Current
      +       1.523E-05 * Angle       * Pressure
      +       5.047E-06 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	0.03290	0.03320	-0.00030
2	0.02850	0.03006	-0.00156
3	0.01260	0.01258	0.00002
4	0.02540	0.02635	-0.00095
5	0.02900	0.02930	-0.00030
6	0.02240	0.02205	0.00035
7	0.03140	0.03105	0.00035
8	0.03910	0.03908	0.00002
9	0.03120	0.03150	-0.00030
10	0.03190	0.03006	0.00184
11	0.03120	0.03291	-0.00171
12	0.03520	0.03526	-0.00006
13	0.02900	0.02809	0.00091
14	0.03630	0.03291	0.00339
15	0.02140	0.02146	-0.00006
16	0.03280	0.03286	-0.00006
17	0.03390	0.03291	0.00099
18	0.03410	0.03416	-0.00006
19	0.03400	0.03309	0.00091
20	0.02860	0.03291	-0.00431
21	0.03550	0.03459	0.00091

□

Table B3. 3/16" 85/15 Statistical Analysis of Microhardness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	46652.6	1	46652.6		
Linear	123.8	4	31.0	2.138	0.1232
Quadratic	201.9	10	20.2	4.069	0.0497
Cubic	20.4	2	10.2	4.325	0.1000
RESIDUAL	9.4	4	2.4		
TOTAL	47008.1	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	222.3	12	18.5	7.870	0.0303
Quadratic	20.4	2	10.2	4.325	0.1000
Cubic	0.0	0			
PURE ERR	9.4	4	2.4		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	3.81	0.3483	0.1854	449.53
Quadratic	15	6	2.23	0.9163	0.7208	3496.15
Cubic	17	4	1.53	0.9735	0.8676	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	325.8	14	23.27	4.689	0.0336
RESIDUAL	29.8	6	4.96		
Lack Of Fit	20.4	2	10.18	4.325	0.1000
Pure Error	9.4	4	2.35		
COR TOTAL	355.5	20			

ROOT MSE	2.23	R-SQUARED	0.9163
DEP MEAN	47.13	ADJ R-SQUARED	0.7208
C.V.	4.73%		

Predicted Residual Sum of Squares (PRESS) = 3496.1

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	47.00	1	0.84	56.20	
A	6.61	1	1.32	5.013	0.0024
B	-0.86	1	4.13	-0.2072	0.8427
C	-0.05	1	1.58	-3.17E-02	0.9757
D	4.25	1	1.58	2.698	0.0357
A2	-2.37	1	1.32	-1.792	0.1232

B2	0.38	1	2.26	0.1694	0.8711
C2	2.09	1	1.28	1.632	0.1539
D2	-1.61	1	1.22	-1.324	0.2336
AB	11.97	1	3.02	3.963	0.0074
AC	6.63	1	3.17	2.090	0.0816
AD	-6.95	1	3.43	-2.029	0.0888
BC	-1.80	1	1.48	-1.217	0.2694
BD	9.65	1	2.30	4.205	0.0057
CD	-5.07	1	3.39	-1.494	0.1857

Final Equation in Terms of Actual Factors:

Microhard =

```
                 25.57
    +           6.4399 * Spray Dist
    -           5.7801 * Angle
    +          0.23349 * Current
    +           3.6464 * Pressure
    -          0.26347 * Spray Dist^2
    +        7.556E-04 * Angle      ^2
    +        2.093E-04 * Current^2
    -        1.611E-02 * Pressure^2
    +          0.17727 * Spray Dist * Angle
    +        2.208E-02 * Spray Dist * Current
    -          0.23176 * Spray Dist * Pressure
    -        8.002E-04 * Angle        * Current
    +        4.291E-02 * Angle        * Pressure
    -        5.072E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	50.20	49.95	0.25
2	38.20	38.01	0.19
3	49.90	49.42	0.48
4	41.00	41.22	-0.22
5	48.50	48.25	0.25
6	49.50	48.78	0.72
7	51.70	50.98	0.72
8	48.00	47.52	0.48
9	51.20	50.95	0.25
10	37.10	38.01	-0.91
11	48.90	47.00	1.90
12	49.80	51.24	-1.44
13	47.50	48.24	-0.74
14	50.00	47.00	3.00
15	48.80	50.24	-1.44
16	47.70	49.14	-1.44
17	48.90	47.00	1.90
18	47.60	49.04	-1.44
19	40.40	41.14	-0.74
20	46.00	47.00	-1.00
21	48.90	49.64	-0.74

□

Table B4. 3/16" 85/15 Statistical Analysis of Oxide Content

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	194.44	1	194.44		
Linear	6.08	4	1.52	4.451	0.0131
Quadratic	4.40	10	0.44	2.475	0.1398
Cubic	0.80	2	0.40	5.976	0.0629
RESIDUAL	0.27	4	0.07		
TOTAL	205.99	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	5.20	12	0.43	6.479	0.0427
Quadratic	0.80	2	0.40	5.976	0.0629
Cubic	0.00	0			
PURE ERR	0.27	4	0.07		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	0.585	0.5267	0.4084	8.944
Quadratic	15	6	0.422	0.9076	0.6922	161.788
Cubic	17	4	0.259	0.9768	0.8842	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	10.48	14	0.749	4.212	0.0433
RESIDUAL	1.07	6	0.178		
Lack Of Fit	0.80	2	0.400	5.976	0.0629
Pure Error	0.27	4	0.067		
COR TOTAL	11.55	20			

ROOT MSE	0.422	R-SQUARED	0.9076
DEP MEAN	3.043	ADJ R-SQUARED	0.6922
C.V.	13.86%		

Predicted Residual Sum of Squares (PRESS) = 161.79

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	3.257	1	0.158	20.57	
A	0.811	1	0.250	3.247	0.0175
B	1.619	1	0.782	2.069	0.0840
C	-0.150	1	0.298	-0.5031	0.6328
D	-0.100	1	0.298	-0.3354	0.7488

A2	-0.880	1	0.250	-3.515	0.0126
B2	0.967	1	0.427	2.263	0.0643
C2	-0.019	1	0.243	-7.84E-02	0.9400
D2	0.348	1	0.230	1.512	0.1812
AB	-0.754	1	0.572	-1.319	0.2351
AC	-0.666	1	0.600	-1.109	0.3098
AD	1.543	1	0.649	2.378	0.0549
BC	-0.088	1	0.280	-0.3133	0.7647
BD	-0.434	1	0.435	-0.998	0.3567
CD	1.471	1	0.643	2.289	0.0620

Final Equation in Terms of Actual Factors:

Oxides =

```
          101.153
-          1.3292 * Spray Dist
+       3.501E-02 * Angle
-         0.12378 * Current
-          1.5104 * Pressure
-       9.780E-02 * Spray Dist^2
+       1.911E-03 * Angle     ^2
-       1.905E-06 * Current^2
+       3.482E-03 * Pressure^2
-       1.117E-02 * Spray Dist * Angle
-       2.218E-03 * Spray Dist * Current
+       5.142E-02 * Spray Dist * Pressure
-       3.900E-05 * Angle      * Current
-       1.928E-03 * Angle      * Pressure
+       1.471E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	2.600	2.565	0.035
2	1.600	1.565	0.035
3	2.300	2.404	-0.104
4	3.600	3.287	0.313
5	2.100	2.065	0.035
6	3.600	3.843	-0.243
7	2.300	2.543	-0.243
8	4.200	4.304	-0.104
9	3.400	3.365	0.035
10	1.600	1.565	0.035
11	3.200	3.257	-0.057
12	3.500	3.188	0.312
13	2.500	2.605	-0.105
14	2.700	3.257	-0.557
15	4.200	3.888	0.312
16	3.700	3.388	0.312
17	3.000	3.257	-0.257
18	3.400	3.088	0.312
19	3.600	3.705	-0.105
20	3.400	3.257	0.143
21	3.400	3.505	-0.105

□

Table B5. 3/16" 85/15 Statistical Analysis of Porosity

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	1182.8	1	1182.8		
Linear	407.6	4	101.9	14.00	0.0001
Quadratic	95.2	10	9.5	2.690	0.1191
Cubic	9.5	2	4.8	1.624	0.3045
RESIDUAL	11.7	4	2.9		
TOTAL	1706.8	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	104.7	12	8.7	2.979	0.1513
Quadratic	9.5	2	4.8	1.624	0.3045
Cubic	0.0	0			
PURE ERR	11.7	4	2.9		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	2.70	0.7778	0.7223	323.29
Quadratic	15	6	1.88	0.9595	0.8649	1735.84
Cubic	17	4	1.71	0.9776	0.8882	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	502.9	14	35.92	10.15	0.0046
RESIDUAL	21.2	6	3.54		
Lack Of Fit	9.5	2	4.76	1.624	0.3045
Pure Error	11.7	4	2.93		
COR TOTAL	524.1	20			

ROOT MSE	1.88	R-SQUARED	0.9595
DEP MEAN	7.50	ADJ R-SQUARED	0.8649
C.V.	25.07%		

Predicted Residual Sum of Squares (PRESS) = 1735.8

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	4.88	1	0.71	6.906	
A	3.82	1	1.11	3.432	0.0139
B	-1.03	1	3.49	-0.2959	0.7773
C	-0.80	1	1.33	-0.6013	0.5696
D	0.50	1	1.33	0.3758	0.7200

A2	0.86	1	1.12	0.7739	0.4684
B2	1.73	1	1.91	0.9075	0.3991
C2	0.99	1	1.08	0.9131	0.3964
D2	-0.84	1	1.03	-0.8139	0.4468
AB	2.26	1	2.55	0.8869	0.4093
AC	-1.68	1	2.68	-0.6290	0.5525
AD	-1.55	1	2.89	-0.5351	0.6118
BC	-0.79	1	1.25	-0.6353	0.5487
BD	0.84	1	1.94	0.4315	0.6812
CD	2.41	1	2.87	0.8414	0.4324

Final Equation in Terms of Actual Factors:

Porosity =

	29.10	
+	3.6569	* Spray Dist
-	1.2112	* Angle
-	0.23620	* Current
+	1.0078	* Pressure
+	9.608E-02	* Spray Dist^2
+	3.419E-03	* Angle ^2
+	9.894E-05	* Current^2
-	8.361E-03	* Pressure^2
+	3.351E-02	* Spray Dist * Angle
-	5.614E-03	* Spray Dist * Current
-	5.162E-02	* Spray Dist * Pressure
-	3.529E-04	* Angle * Current
+	3.718E-03	* Angle * Pressure
+	2.412E-03	* Current * Pressure

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	6.70	6.62	0.08
2	1.80	1.92	-0.12
3	21.20	20.84	0.36
4	6.00	6.47	-0.47
5	1.40	1.32	0.08
6	14.70	14.07	0.63
7	10.00	9.37	0.63
8	9.10	8.74	0.36
9	16.00	15.92	0.08
10	1.60	1.92	-0.32
11	8.20	4.88	3.32
12	8.50	9.57	-1.07
13	7.40	7.64	-0.24
14	6.10	4.88	1.22
15	12.80	13.87	-1.07
16	5.60	6.67	-1.07
17	5.50	4.88	0.62
18	4.00	5.07	-1.07
19	3.30	3.54	-0.24
20	3.40	4.88	-1.48
21	4.30	4.54	-0.24

□

Table B6. 3/16" 85/15 Statistical Analysis of Roughness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	4674.1	1	4674.1		
Linear	361.6	4	90.4	13.49	0.0001
Quadratic	87.0	10	8.7	2.585	0.1286
Cubic	8.2	2	4.1	1.375	0.3511
RESIDUAL	12.0	4	3.0		
TOTAL	5143.0	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	95.2	12	7.9	2.653	0.1792
Quadratic	8.2	2	4.1	1.375	0.3511
Cubic	0.0	0			
PURE ERR	12.0	4	3.0		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	2.59	0.7713	0.7142	298.93
Quadratic	15	6	1.83	0.9569	0.8564	1452.44
Cubic	17	4	1.73	0.9745	0.8724	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	448.6	14	32.04	9.523	0.0055
RESIDUAL	20.2	6	3.37		
Lack Of Fit	8.2	2	4.11	1.375	0.3511
Pure Error	12.0	4	2.99		
COR TOTAL	468.8	20			

ROOT MSE	1.83	R-SQUARED	0.9569
DEP MEAN	14.92	ADJ R-SQUARED	0.8564
C.V.	12.30%		

Predicted Residual Sum of Squares (PRESS) = 1452.4

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	11.80	1	0.69	17.13	
A	3.05	1	1.09	2.807	0.0309
B	-0.97	1	3.40	-0.2857	0.7847
C	0.06	1	1.30	4.63E-02	0.9646
D	-1.99	1	1.30	-1.534	0.1759
A2	0.15	1	1.09	0.1382	0.8946

B2	1.64	1	1.86	0.8840	0.4107
C2	1.75	1	1.06	1.657	0.1486
D2	0.72	1	1.00	0.7153	0.5013
AB	-1.46	1	2.49	-0.5853	0.5797
AC	-4.82	1	2.61	-1.847	0.1143
AD	2.16	1	2.82	0.7643	0.4736
BC	0.46	1	1.22	0.3776	0.7188
BD	-2.04	1	1.89	-1.081	0.3212
CD	5.62	1	2.80	2.012	0.0909

Final Equation in Terms of Actual Factors:

Ra Rough. =

```
          265.09
+         1.0914 * Spray Dist
+        0.40303 * Angle
-        0.55800 * Current
-         3.4295 * Pressure
+      1.673E-02 * Spray Dist^2
+      3.247E-03 * Angle      ^2
+      1.750E-04 * Current^2
+      7.164E-03 * Pressure^2
-      2.156E-02 * Spray Dist * Angle
-      1.607E-02 * Spray Dist * Current
+      7.189E-02 * Spray Dist * Pressure
+      2.045E-04 * Angle        * Current
-      9.083E-03 * Angle        * Pressure
+      5.623E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL
1	15.96	15.83	0.13
2	8.80	8.90	-0.10
3	26.82	26.50	0.32
4	14.93	15.19	-0.26
5	10.82	10.69	0.13
6	23.44	22.93	0.51
7	16.11	15.60	0.51
8	17.09	16.77	0.32
9	23.02	22.89	0.13
10	8.56	8.90	-0.34
11	15.26	11.80	3.46
12	14.05	15.00	-0.95
13	14.04	14.42	-0.38
14	12.01	11.80	0.21
15	19.37	20.32	-0.95
16	12.54	13.49	-0.95
17	10.51	11.80	-1.29
18	12.66	13.61	-0.95
19	14.13	14.51	-0.38
20	13.03	11.80	1.23
21	10.15	10.53	-0.38

□

Table B7. Minitab Analysis for 3/16" 85/15

```
MTB > REGRESS C6 20 C1-C5 C7-C21;
SUBC> RESIDUALS C22.

The regression equation is
CML = 0.216 +0.000077 BS - 0.00767 P + 0.0628 O - 0.0160 MH -0.000000 BS2
           +0.000053 R2 +0.000120 P2 - 0.00666 O2 +0.000187 MH2 + 0.026 1/R
           - 0.210 1/P + 0.165 1/O + 0.192 1/P2
```

Predictor	Coef	Stdev	t-ratio	p
Constant	0.2163	0.3765	0.57	0.584
BS	0.0000774	0.0002573	0.30	0.772
P	-0.007671	0.005119	-1.50	0.178
O	0.06284	0.08476	0.74	0.483
MH	-0.015996	0.009589	-1.67	0.139
BS2	-0.00000004	0.00000011	-0.41	0.693
R2	0.00005309	0.00005388	0.99	0.357
P2	0.0001204	0.0001332	0.90	0.396
O2	-0.006655	0.009484	-0.70	0.506
MH2	0.0001869	0.0001070	1.75	0.124
1/R	0.0264	0.2268	0.12	0.911
1/P	-0.2102	0.1642	-1.28	0.241
1/O	0.1648	0.2319	0.71	0.500
1/P2	0.1918	0.1554	1.23	0.257

s = 0.003563 R-sq = 87.5% R-sq(adj) = 64.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	13	0.00062354	0.00004796	3.78	0.043
Error	7	0.00008887	0.00001270		
Total	20	0.00071241			

SOURCE	DF	SEQ SS
BS	1	0.00015572
P	1	0.00031993
O	1	0.00000822
MH	1	0.00004041
BS2	1	0.00000014
R2	1	0.00000106
P2	1	0.00002357
O2	1	0.00000048
MH2	1	0.00005106
1/R	1	0.00000048
1/P	1	0.00000225
1/O	1	0.00000088
1/P2	1	0.00001933

Unusual Observations

Obs.	BS	CML	Fit	Stdev.Fit	Residual	St.Resid
8	1080	0.039100	0.034489	0.002904	0.004611	2.23R

R denotes an obs. with a large st. resid.

RESIDUALS

-0.0015077	0.0001888	-0.0000111	-0.0004910	0.0000373	-0.0005372
-0.0000818	0.0046106	0.0017439	-0.0002158	-0.0023201	0.0027150
0.0021424	-0.0015183	-0.0040734	-0.0035661	0.0010872	0.0030305
0.0005100	-0.0014081	-0.0003350			

Appendix C. Results for the 1/8" Aluminum Wire System

Figures C1-C21: Photomicrographs C1-C21
Figures C22-C27: Perturbation Plots
Tables C1-C6: Design Expert Analysis
Table C7: Minitab Analysis

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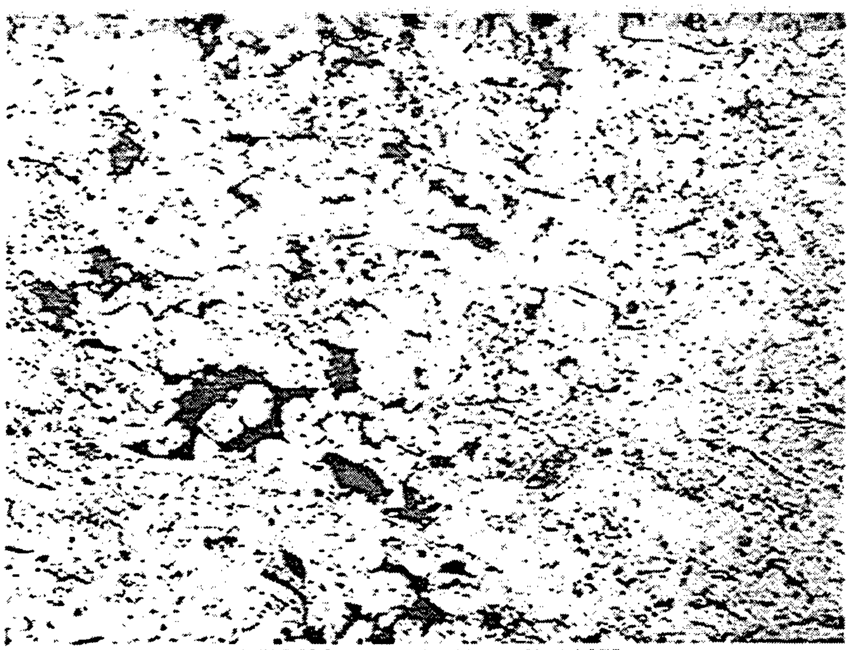

PHOTO 1 TAKEN AT 200X

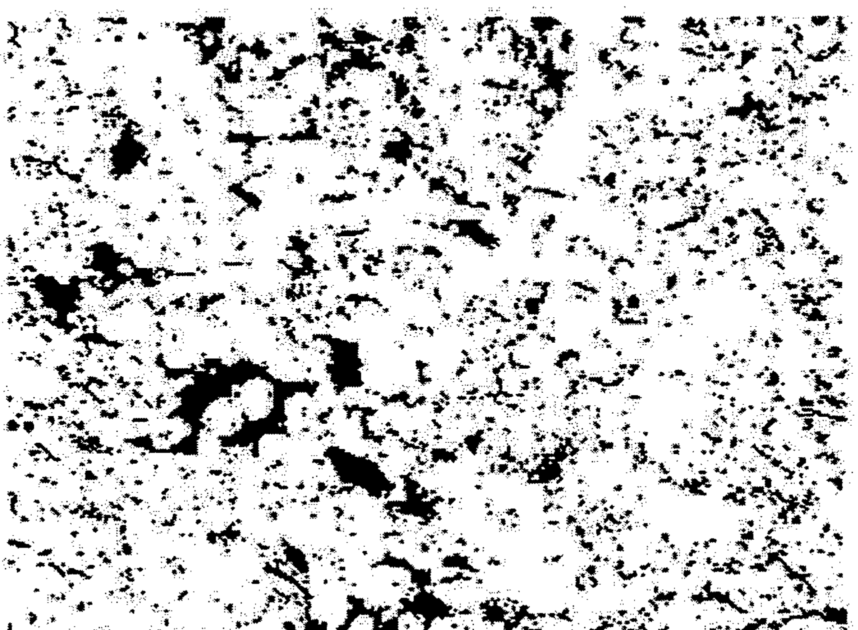

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A1

Figure C1. Photomicrograph of Coating A1 (1/8" aluminum)

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PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A2

Figure C2. Photomicrograph of Coating A2 (1/8" aluminum)

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PHOTO 1 TAKEN AT 200X

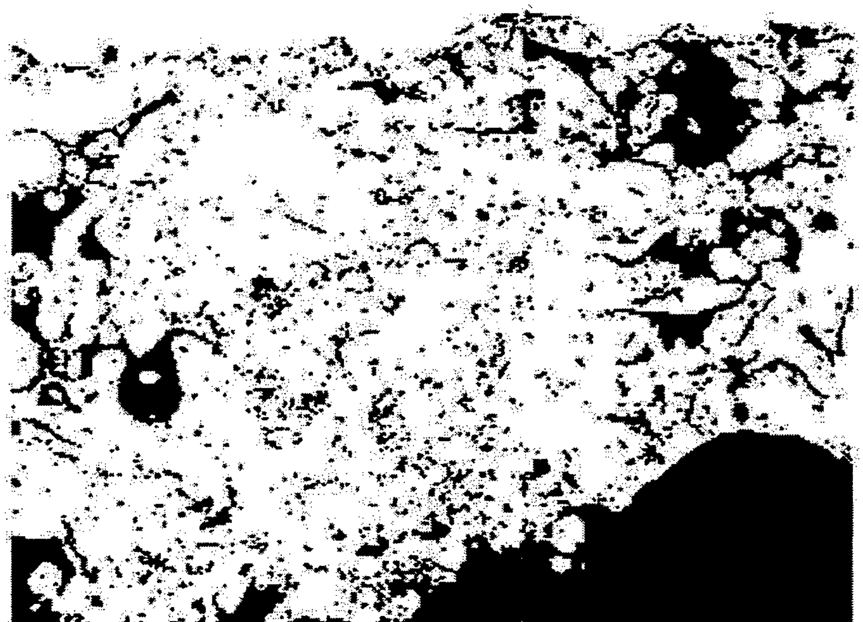

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A3

Figure C3. Photomicrograph of Coating A3 (1/8" aluminum)

PROTECH LAB CORP.
Materials Testing Services
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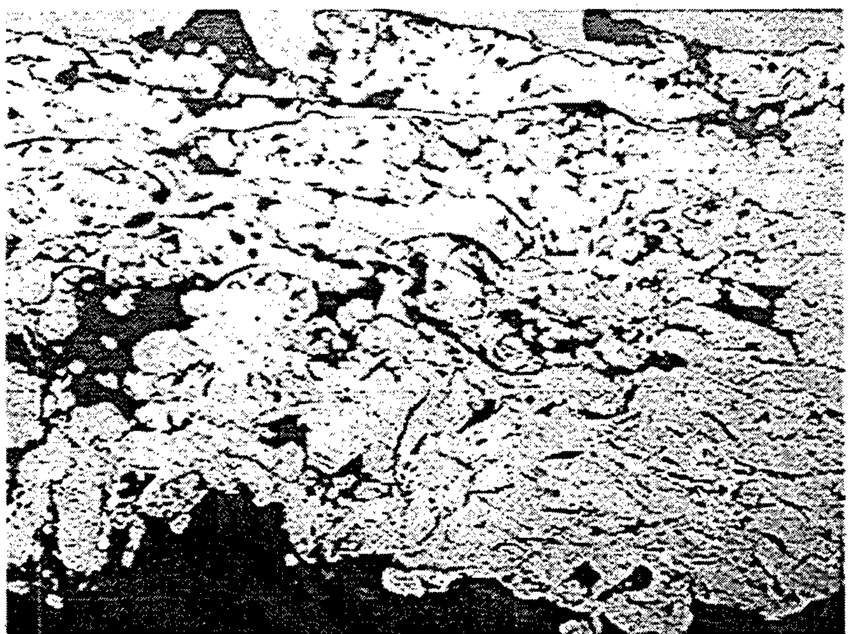

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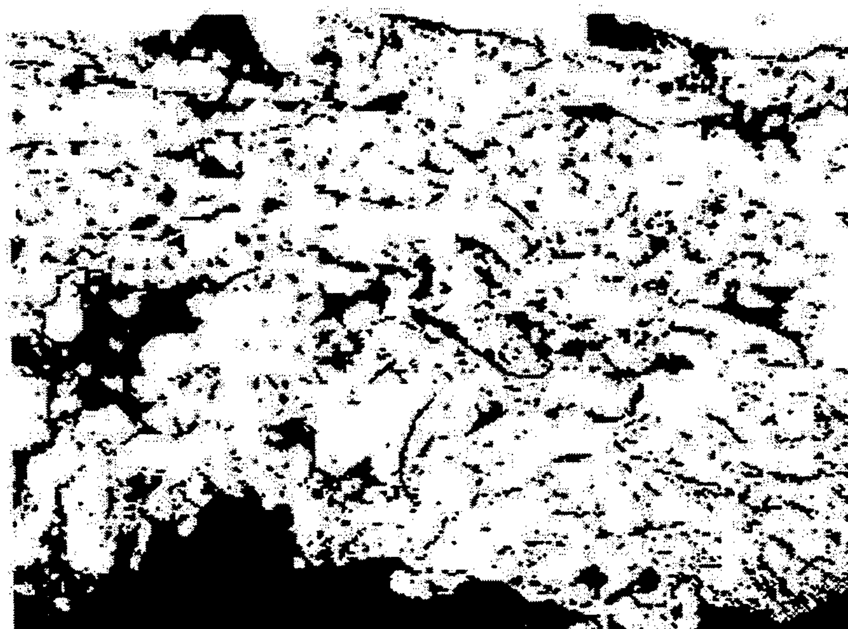

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A4

Figure C4. Photomicrograph of Coating A4 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

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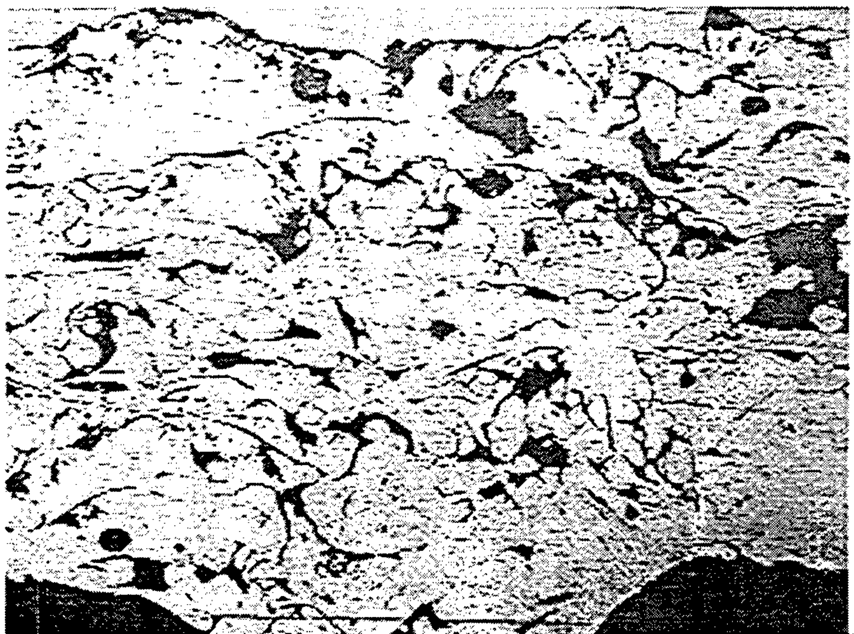

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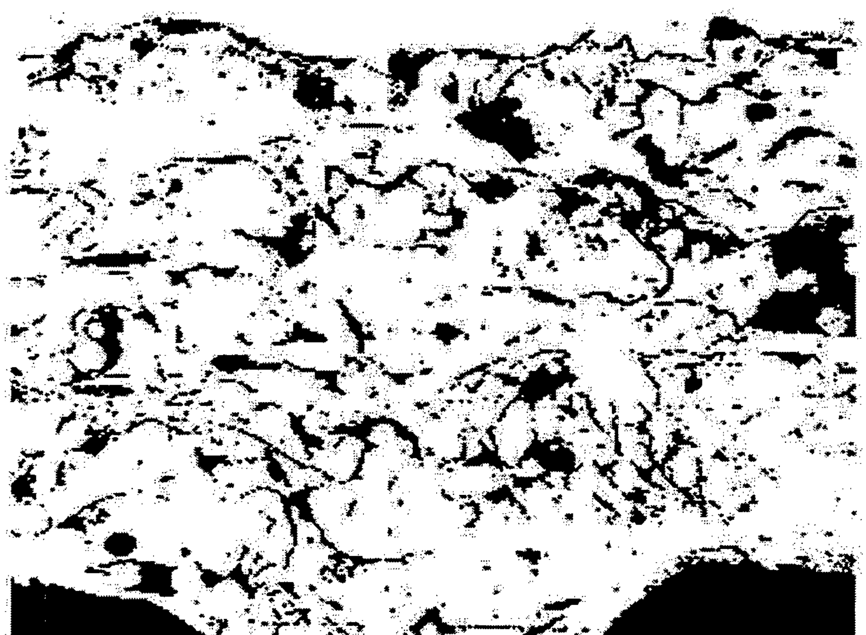

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A5

Figure C5. Photomicrograph of Coating A5 (1/8" aluminum)

PROTECH LAB CORP.
Materials Testing Services
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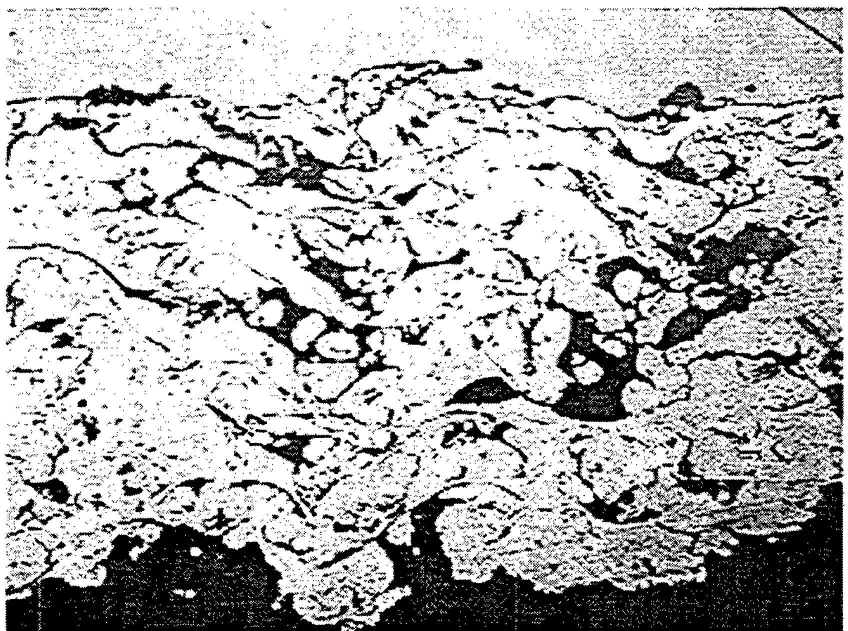

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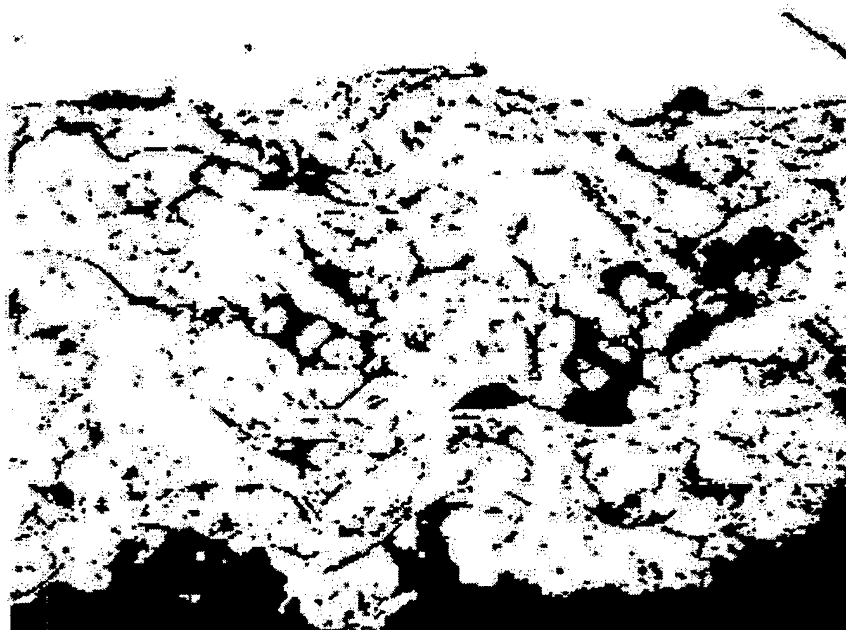

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A6

Figure C6. Photomicrograph of Coating A6 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

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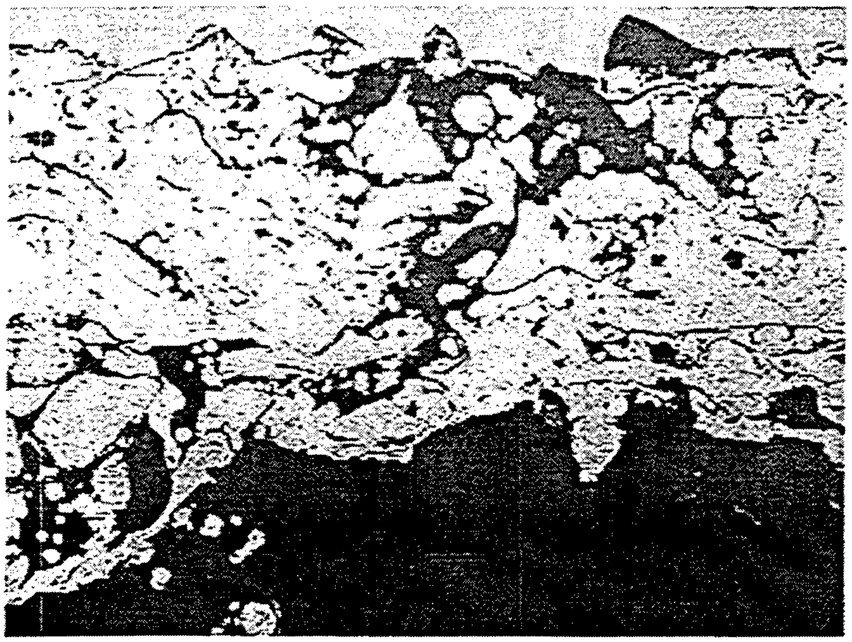

PHOTO 1 TAKEN AT 200X

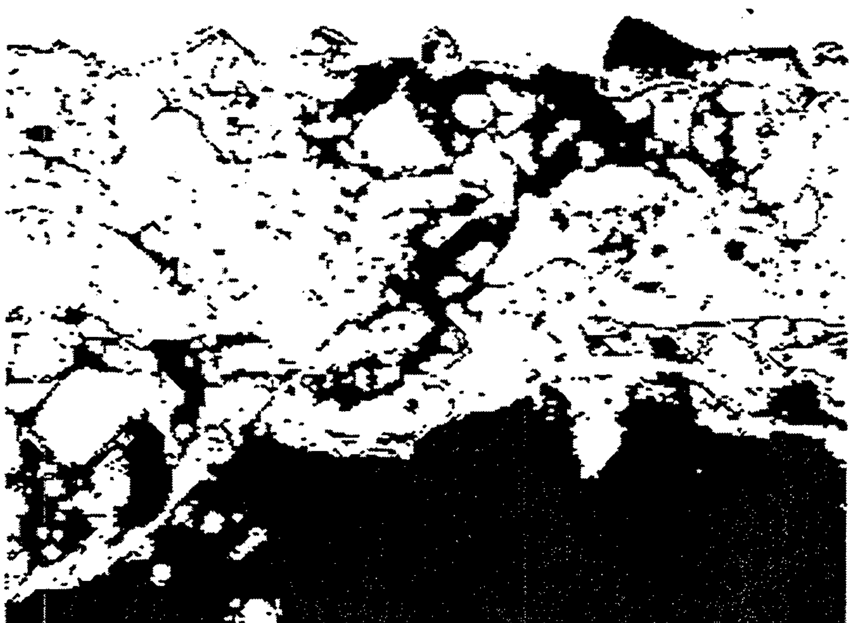

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A7

Figure C7. Photomicrograph of Coating A7 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

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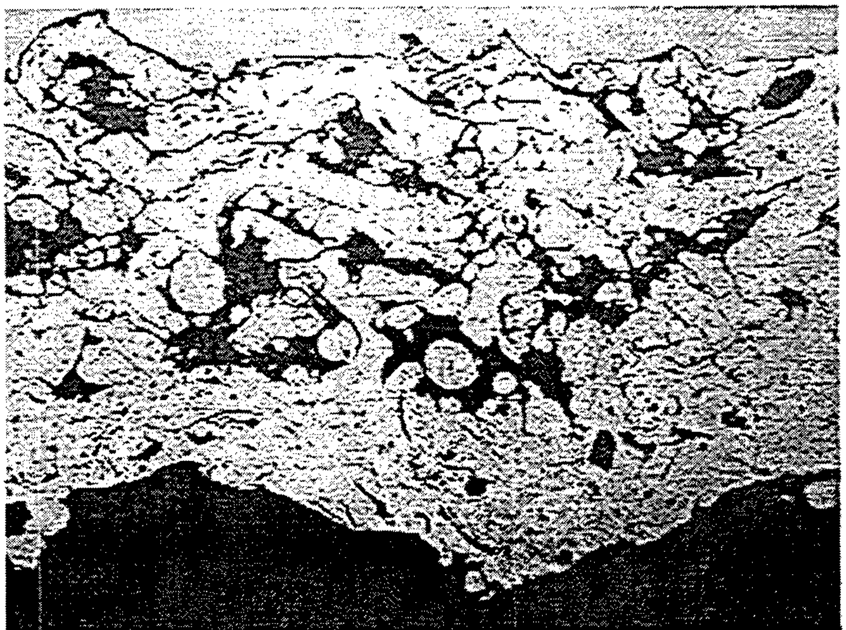

PHOTO 1 TAKEN AT 200X

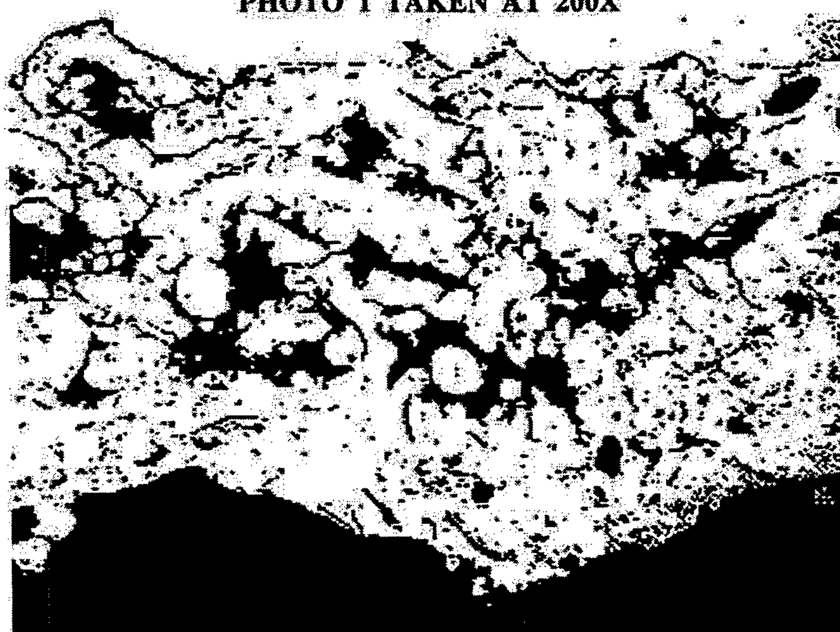

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A8

Figure C8. Photomicrograph of Coating A8 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A9

Figure C9. Photomicrograph of Coating A9 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

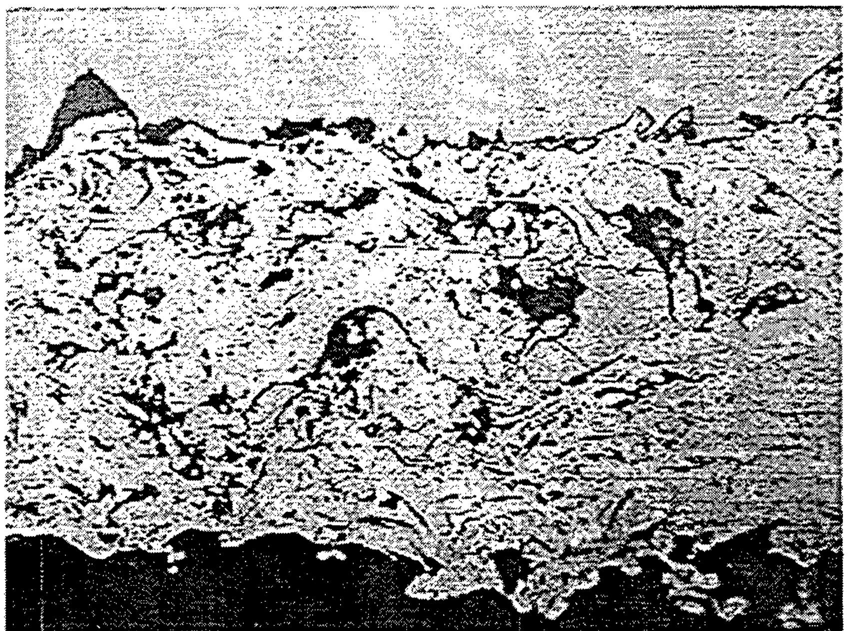

PHOTO 1 TAKEN AT 200X

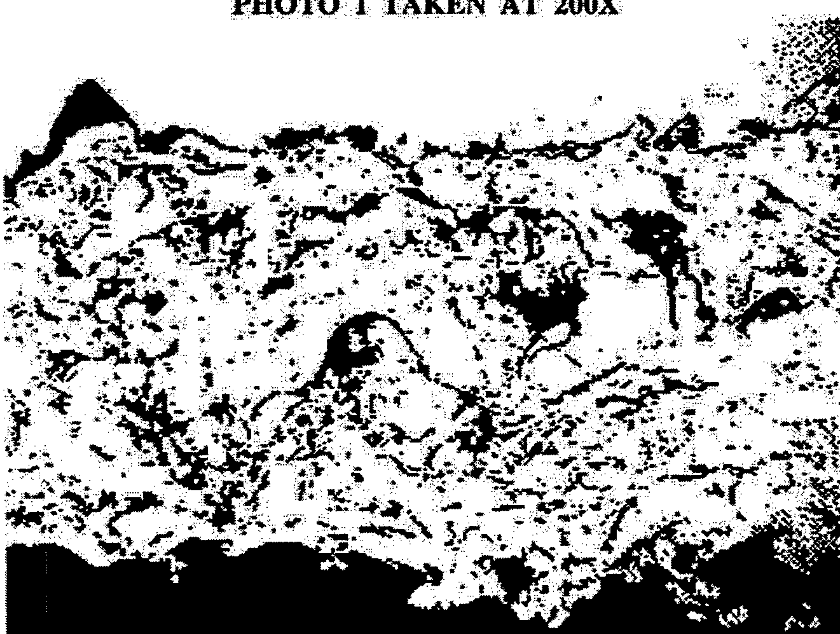

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A10

Figure C10. Photomicrograph of Coating A10 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

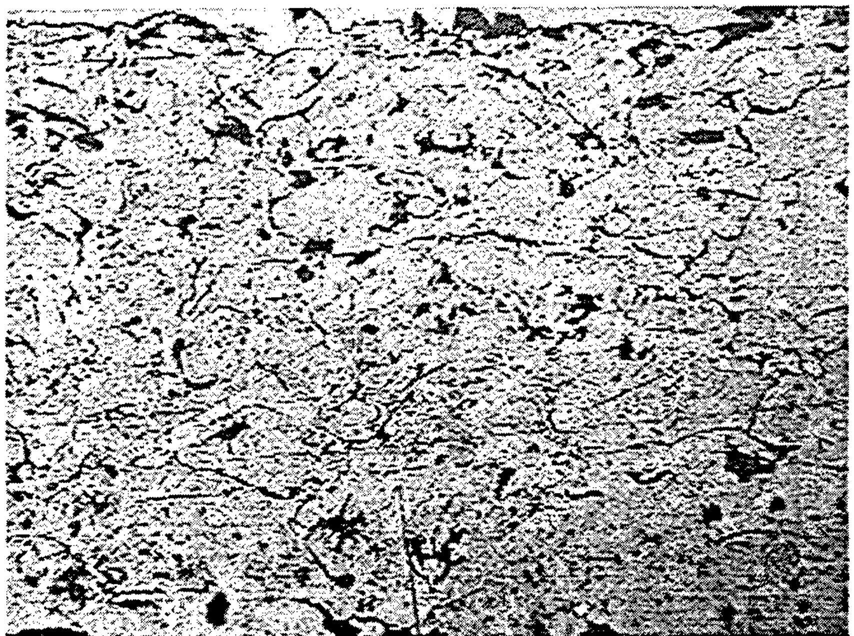

PHOTO 1 TAKEN AT 200X

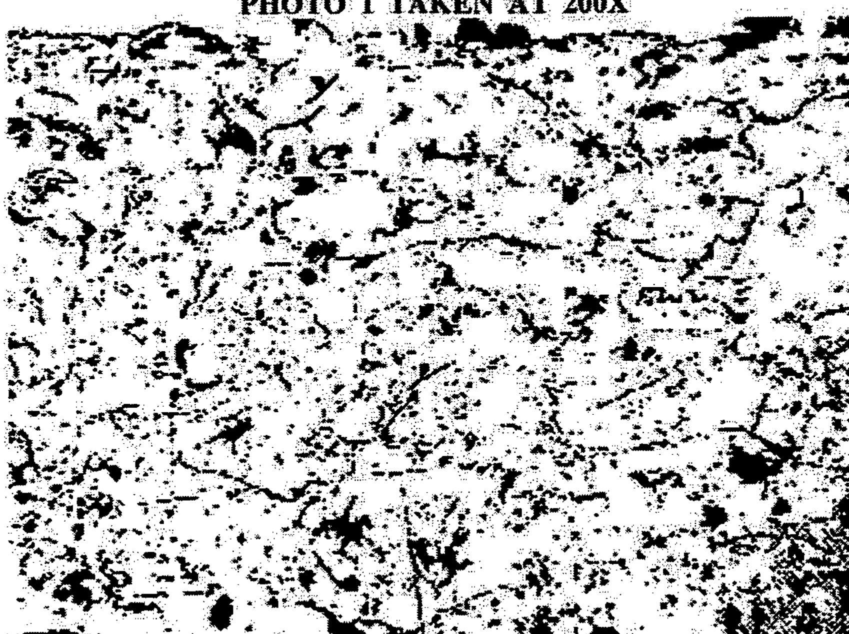

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A11

Figure C11. Photomicrograph of Coating A11 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

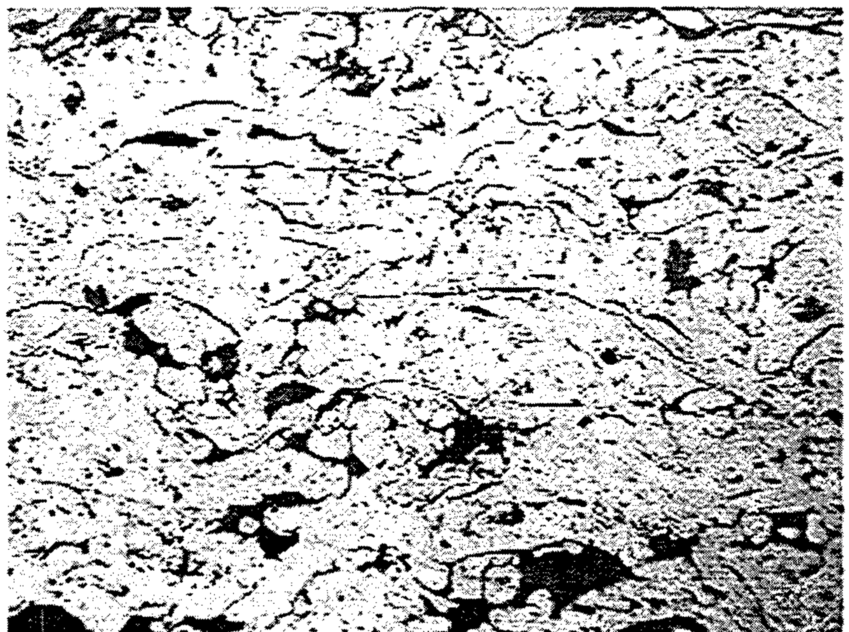

PHOTO 1 TAKEN AT 200X

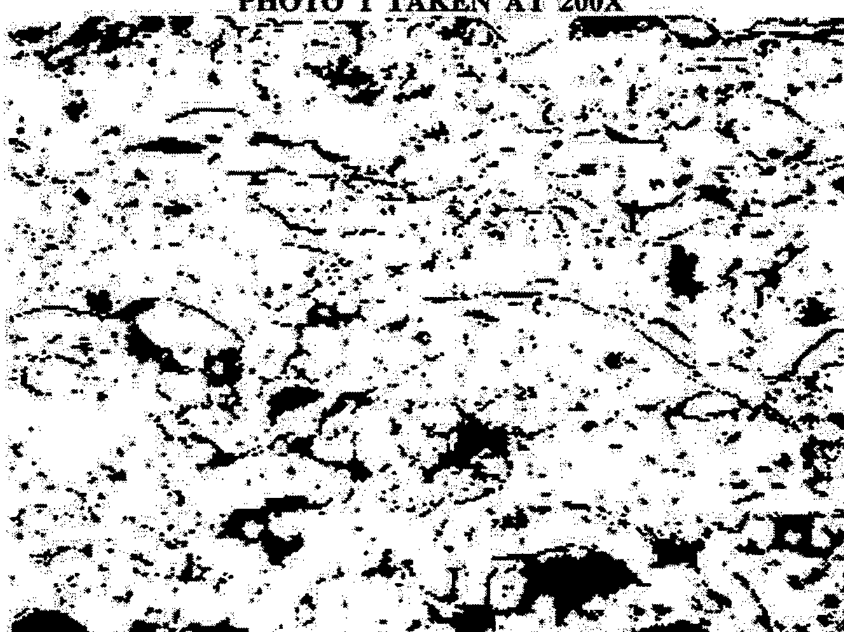

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A12

Figure C12. Photomicrograph of Coating A12 (1/8" aluminum)

PROTECH LAB CORP.
Materials Testing Services
9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

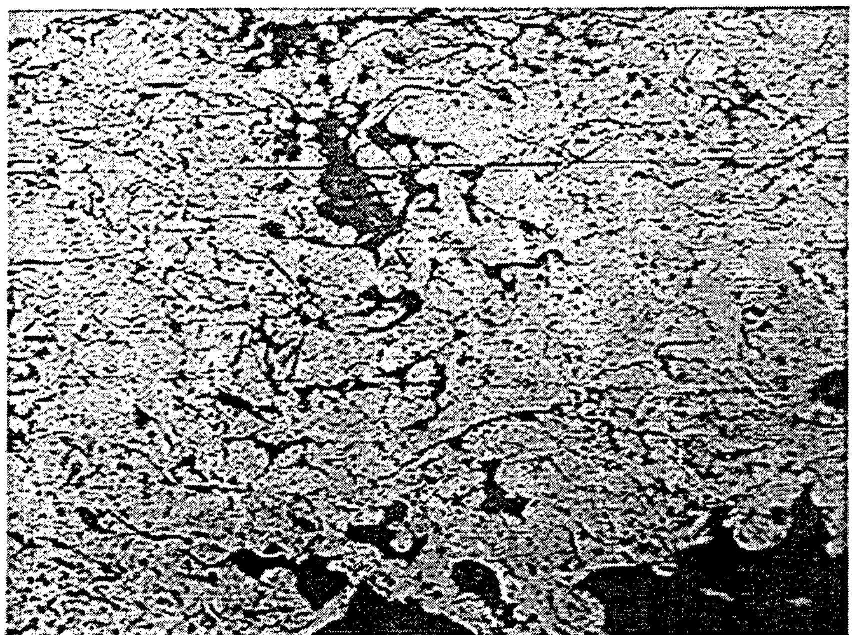

PHOTO 1 TAKEN AT 200X

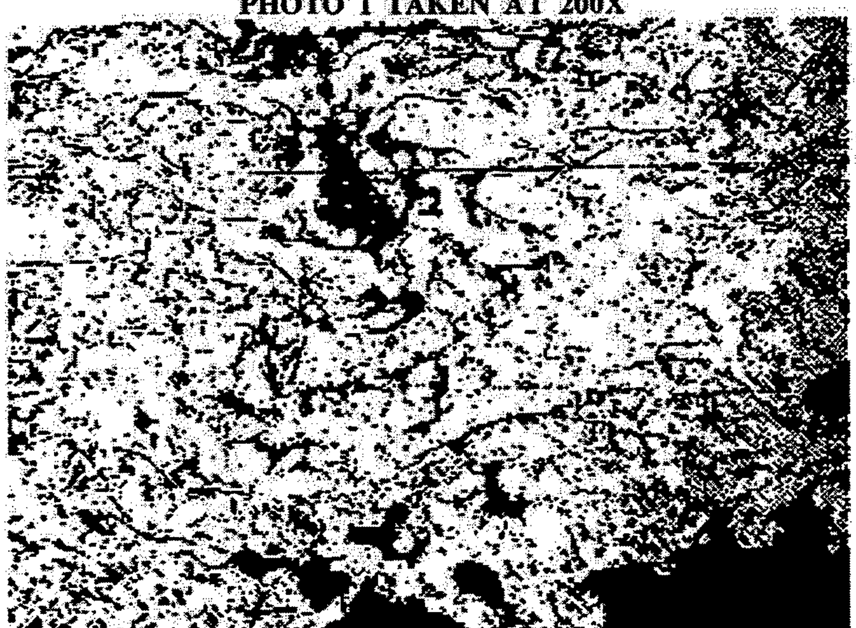

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A13

Figure C13. Photomicrograph of Coating A13 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

PHOTO 1 TAKEN AT 200X

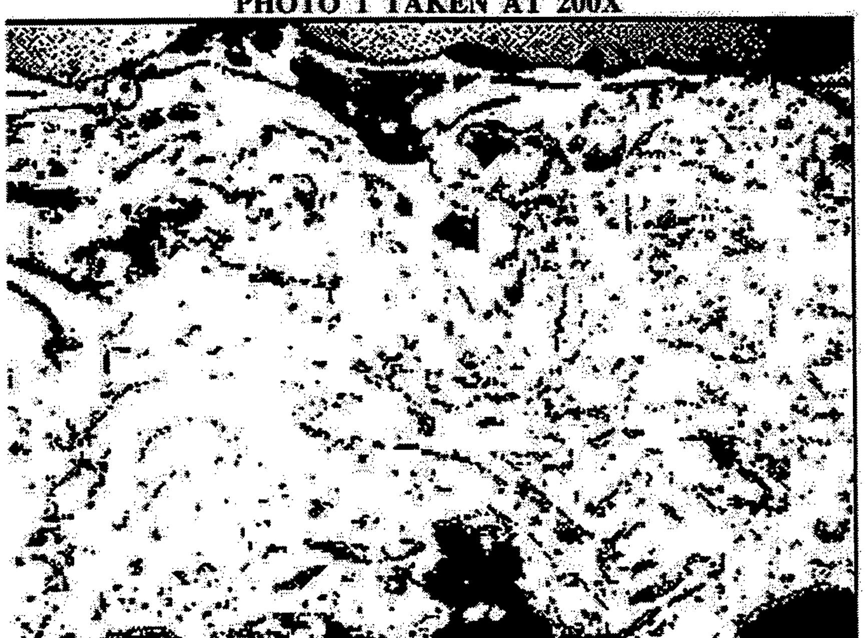

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A14

Figure C14. Photomicrograph of Coating A14 (1/8" aluminum)

PROTECH LAB CORP.
Materials Testing Services
9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

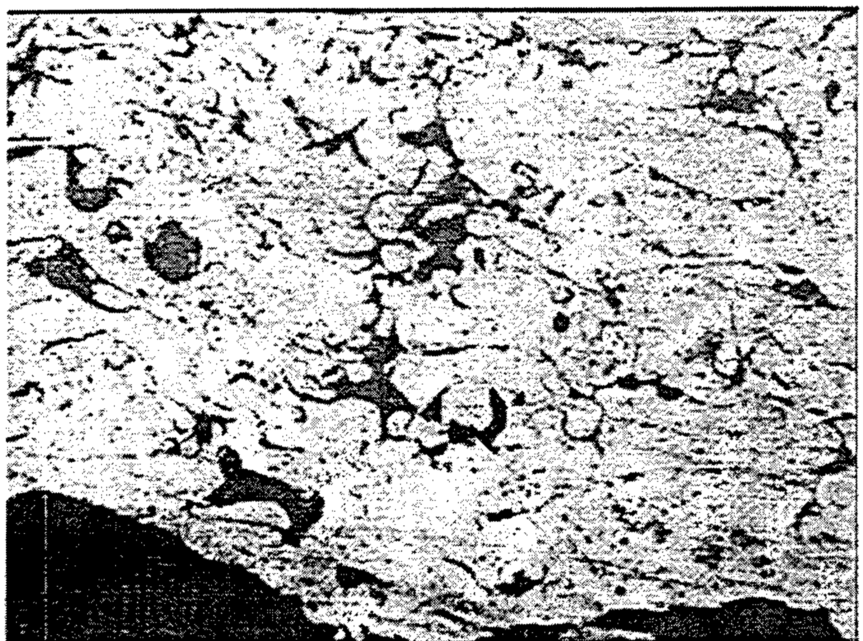

PHOTO 1 TAKEN AT 200X

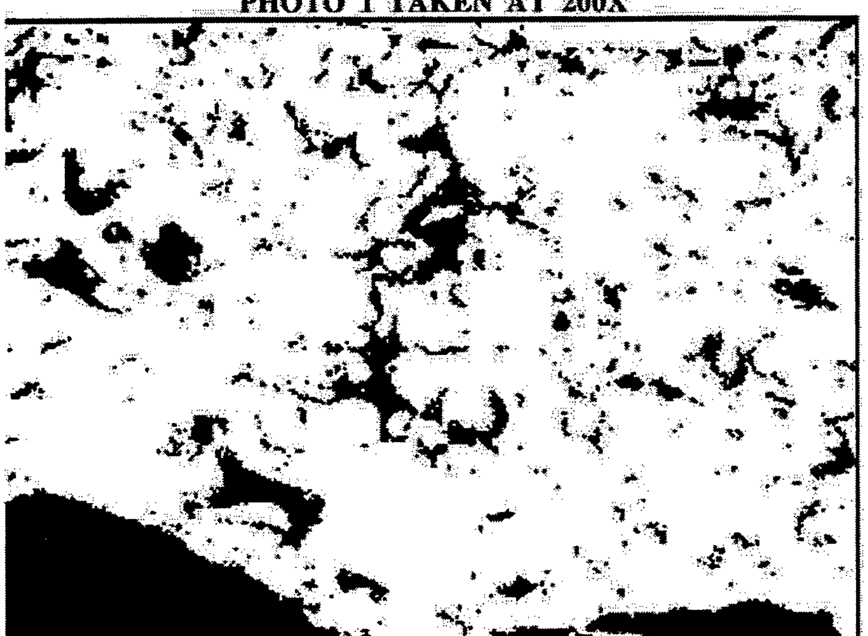

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A15

Figure C15. Photomicrograph of Coating A15 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A16

Figure C16. Photomicrograph of Coating A16 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

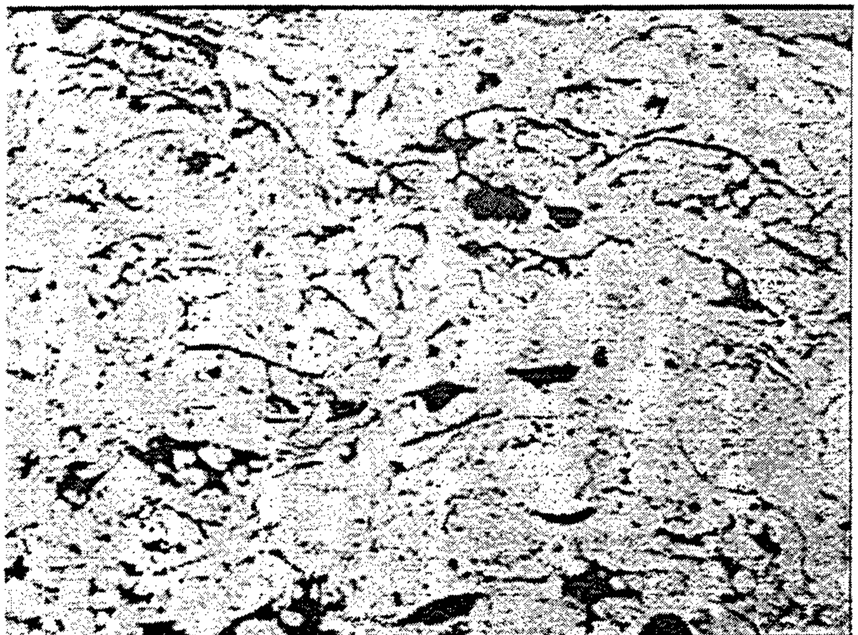

PHOTO 1 TAKEN AT 200X

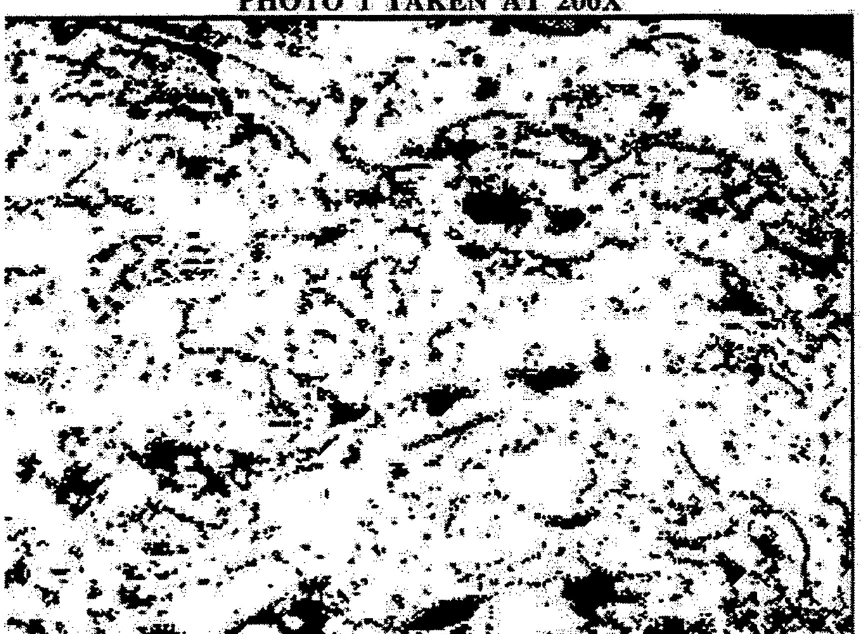

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A17

Figure C17. Photomicrograph of Coating A17 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

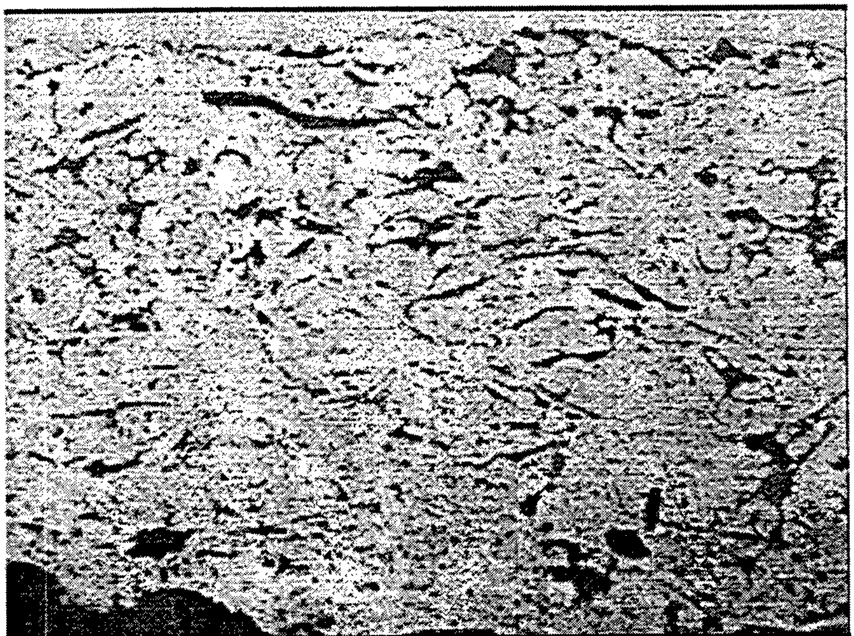

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A18

Figure C18. Photomicrograph of Coating A18 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

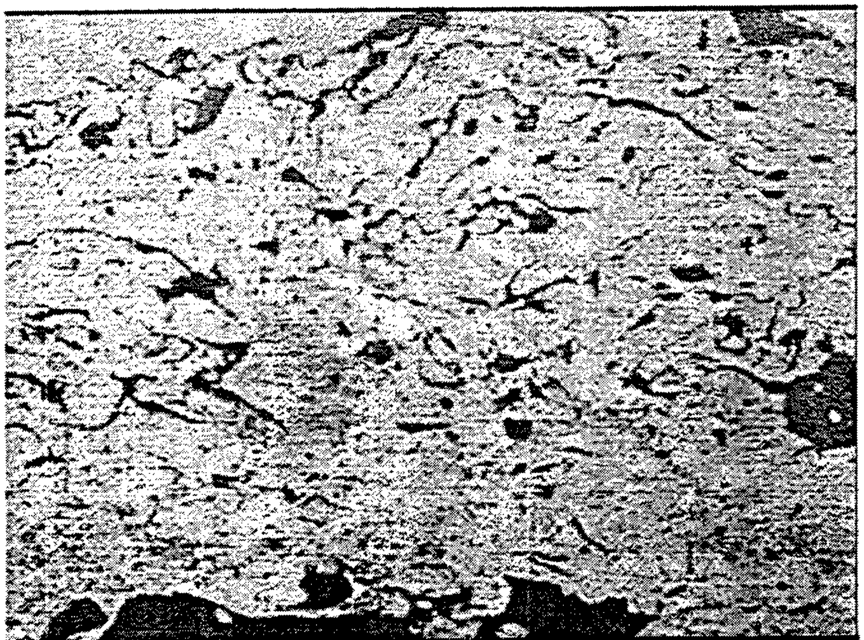

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A19

Figure C19. Photomicrograph of Coating A19 (1/8" aluminum)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

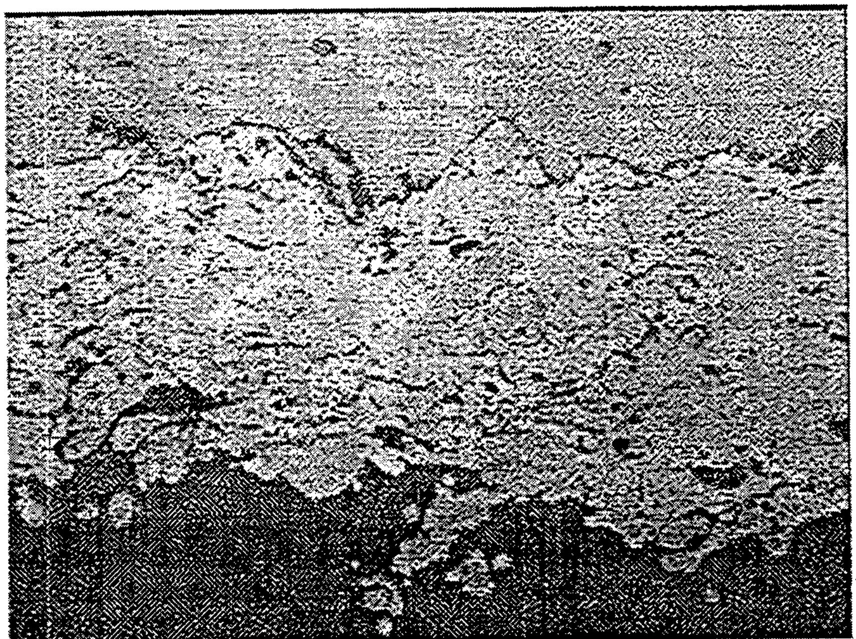

PHOTO 1 TAKEN AT 200X

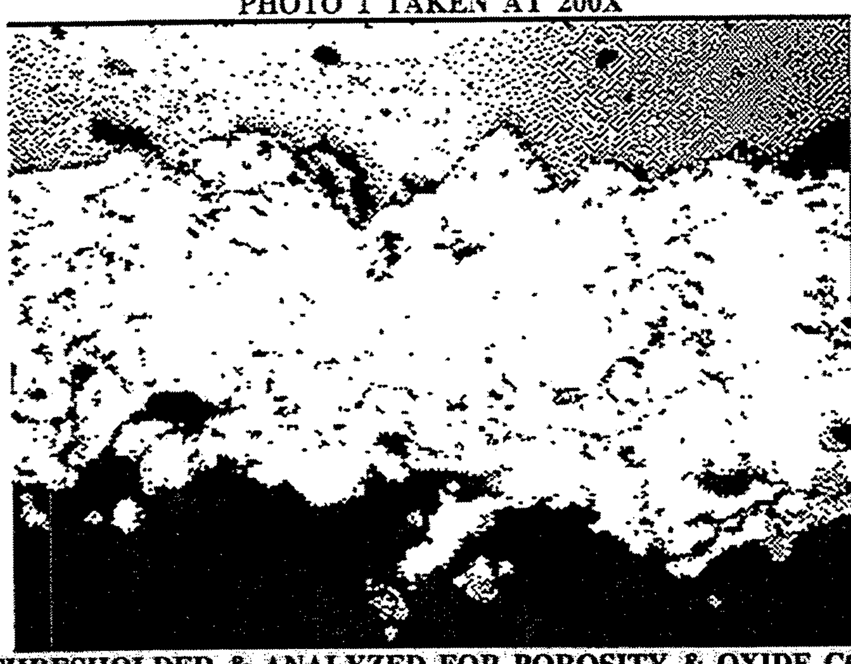

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A20

Figure C20. Photomicrograph of Coating A20 (1/8" aluminum)

PROTECH LAB CORP.
Materials Testing Services
9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

PHOTO 1 TAKEN AT 200X

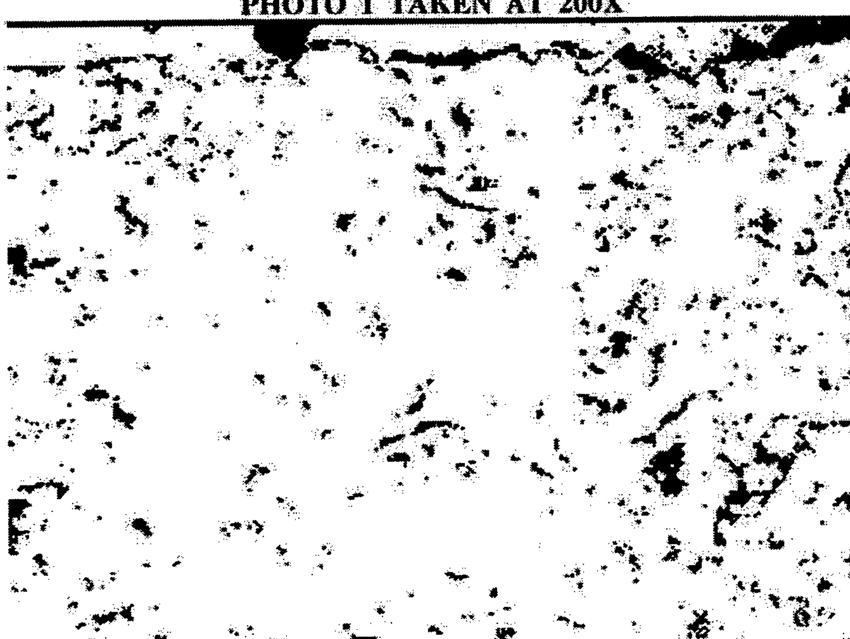

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-A21

Figure C21. Photomicrograph of Coating A21 (1/8" aluminum)

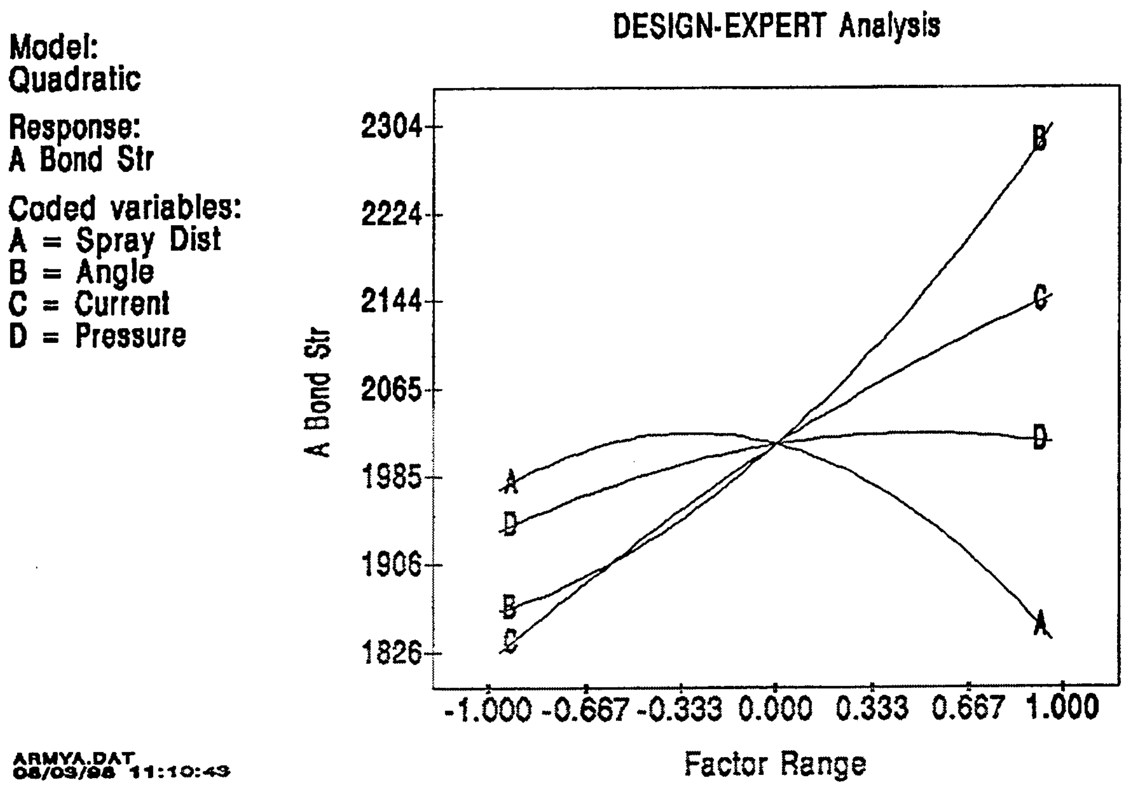

Figure C22. Bond Strength Parameter Plot for 1/8" Al Coatings

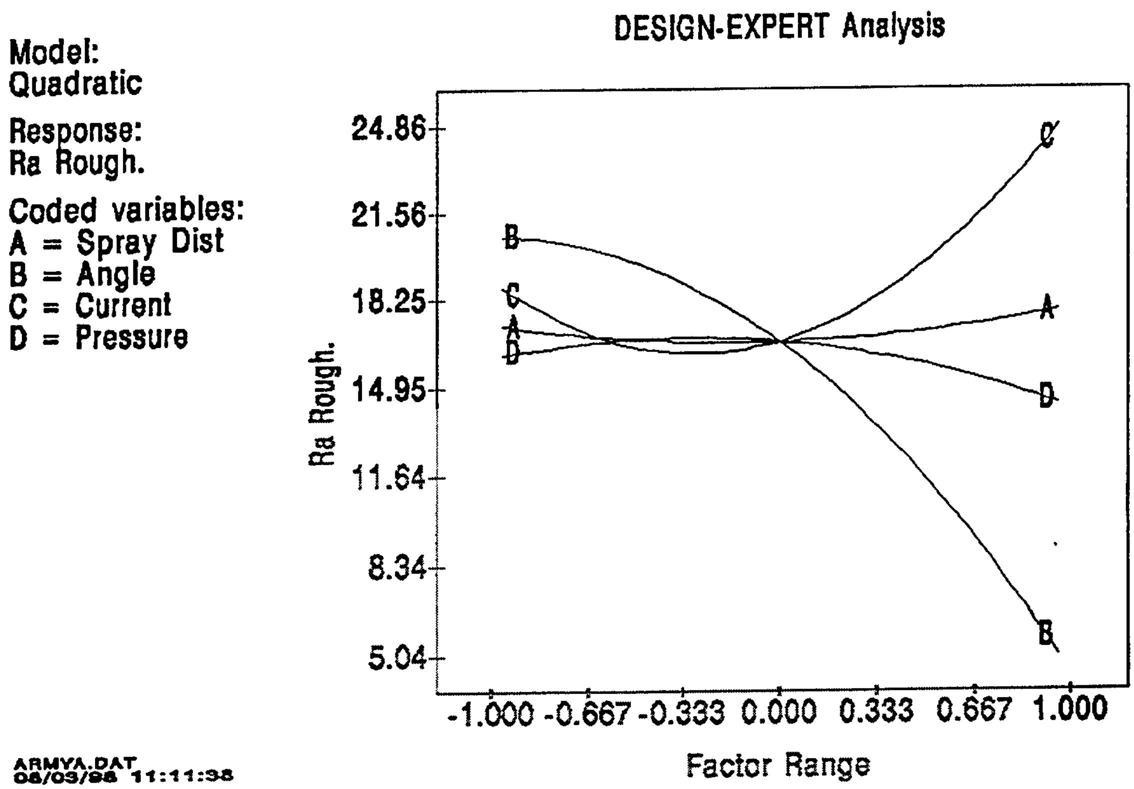

Figure C23. Roughness Parameter Plot for 1/8" Al Coatings

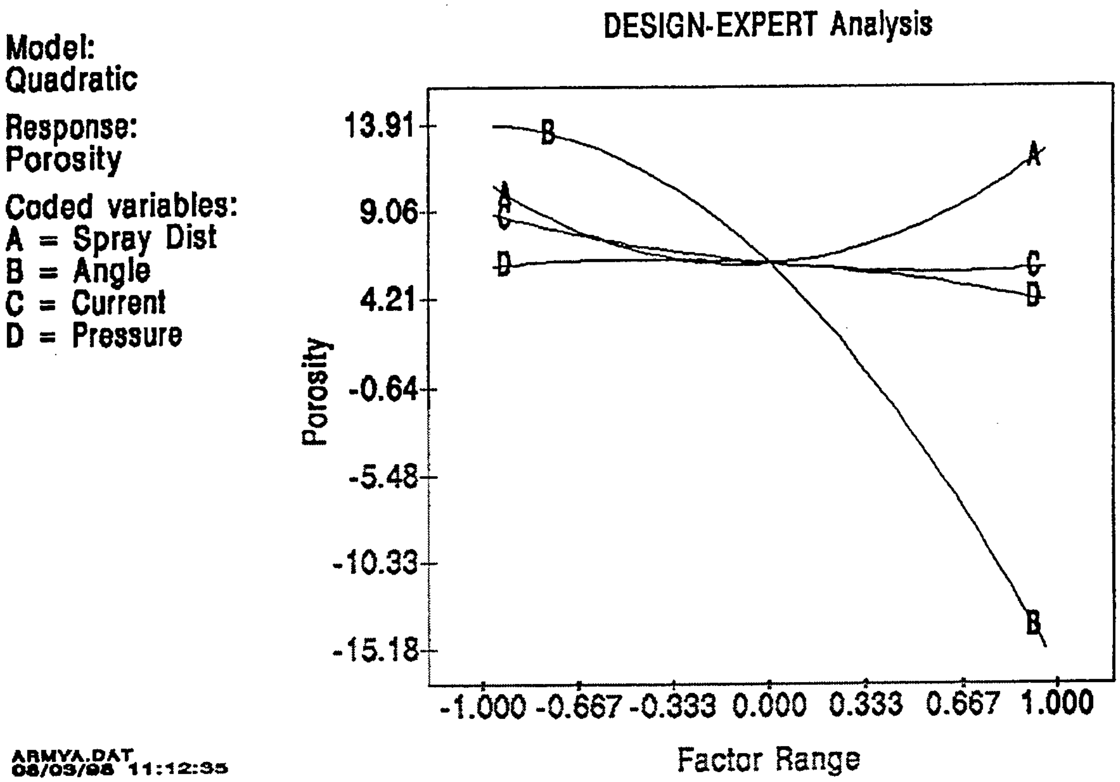

Figure C24. Porosity Parameter Plot for 1/8" Al Coatings

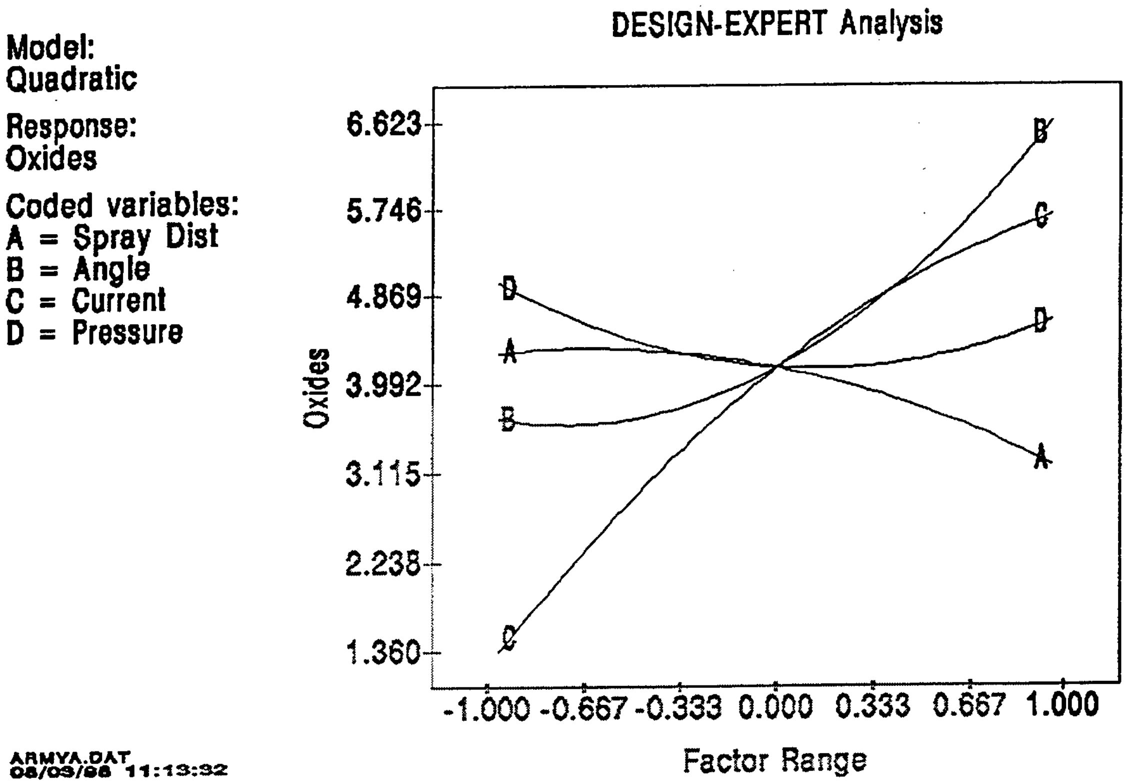

Figure C25. Oxides Parameter Plot for 1/8" Al Coatings

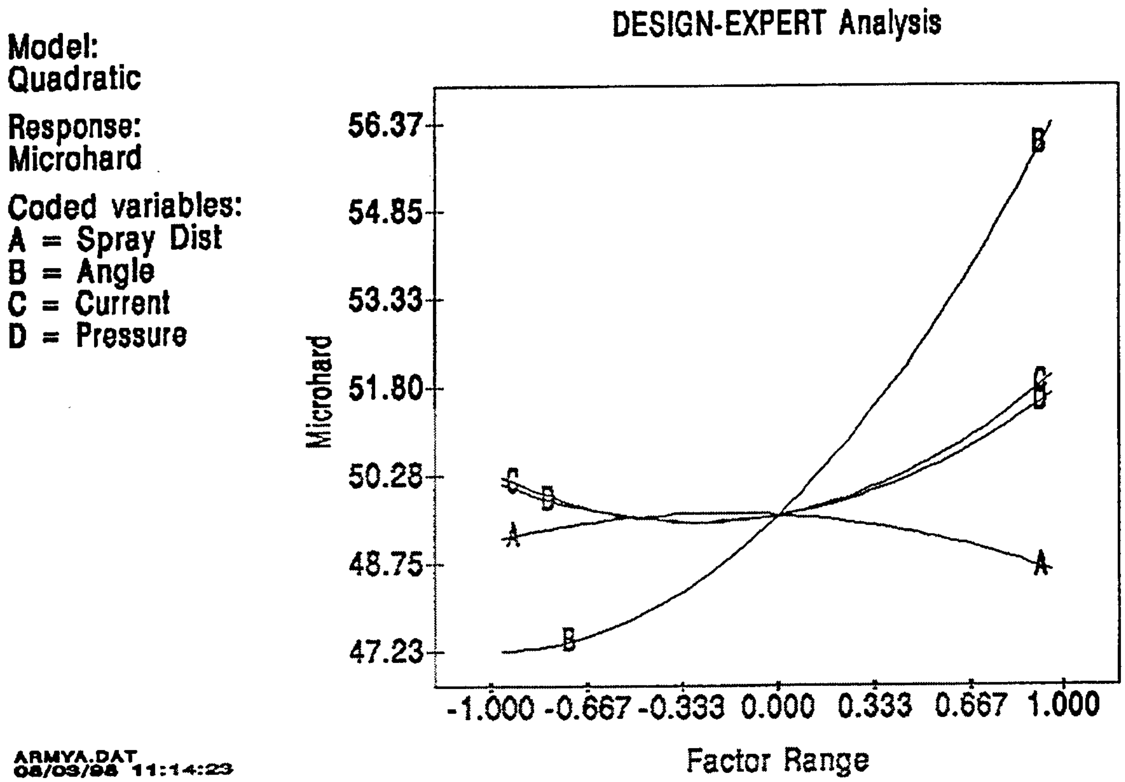

Figure C26. Hardness Parameter Plot for 1/8" Al Coatings

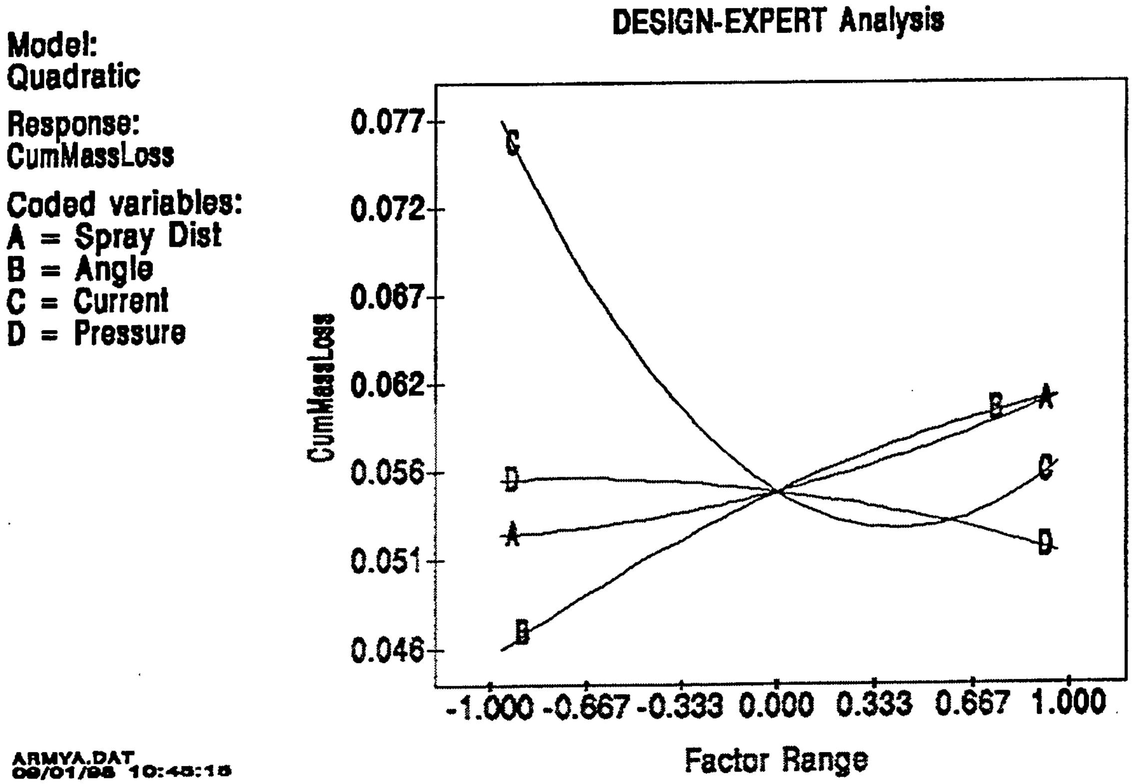

Figure C27. CML Parameter Plot for 1/8" Al Coatings

Table C1. 1/8" Aluminum Statistical Analysis of Bond Strength

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	74512202.3	1	74512202.3		
Linear	425682.7	4	106420.7	7.926	0.0010
Quadratic	141475.4	10	14147.5	1.157	0.4480
Cubic	18523.6	2	9261.8	0.6758	0.5587
RESIDUAL	54821.0	4	13705.2		
TOTAL	75152705.0	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	159999.0	12	13333.2	0.9729	0.5679
Quadratic	18523.6	2	9261.8	0.6758	0.5587
Cubic	0.0	0			
PURE ERR	54821.0	4	13705.2		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	115.9	0.6646	0.5808	471251.8
Quadratic	15	6	110.6	0.8855	0.6183	3236782.9
Cubic	17	4	117.1	0.9144	0.5720	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	567158.1	14	40511.3	3.314	0.0743
RESIDUAL	73344.6	6	12224.1		
Lack Of Fit	18523.6	2	9261.8	0.6758	0.5587
Pure Error	54821.0	4	13705.3		
COR TOTAL	640502.7	20			

ROOT MSE	110.6	R-SQUARED	0.8855
DEP MEAN	1883.7	ADJ R-SQUARED	0.6183
C.V.	5.87%		

Predicted Residual Sum of Squares (PRESS) = 3236782.9

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	2014.5	1	41.5	48.53	
A	-70.2	1	65.5	-1.071	0.3252
B	228.9	1	205.2	1.115	0.3073
C	168.0	1	78.2	2.149	0.0752

D2	-41.6	1	60.4	-0.6885	0.5169
AB	52.3	1	149.9	0.3487	0.7392
AC	91.6	1	157.3	0.5822	0.5817
AD	37.1	1	170.1	0.2182	0.8345
BC	29.6	1	73.4	0.4030	0.7009
BD	-5.3	1	113.9	-4.66E-02	0.9644
CD	22.8	1	168.5	0.1351	0.8970

Final Equation in Terms of Actual Factors:

A Bond Str =

```
            -357.1
-           88.910 * Spray Dist
-           25.814 * Angle
-           2.4601 * Current
+           70.249 * Pressure
-           13.040 * Spray Dist^2
+          0.14874 * Angle     ^2
-        2.953E-03 * Current^2
-          0.41562 * Pressure^2
+          0.77409 * Spray Dist * Angle
+          0.30533 * Spray Dist * Current
+           1.2372 * Spray Dist * Pressure
+        1.315E-02 * Angle      * Current
-        2.357E-02 * Angle      * Pressure
+        2.275E-02 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	1743.0	1761.7	-18.7	0.980	-1.198	4.714	-1.254	1
2	1896.0	1967.3	-71.3	0.492	-0.905	0.053	-0.889	2
3	1896.0	1898.7	-2.7	0.986	-0.203	0.190	-0.186	3
4	1815.0	1865.7	-50.7	0.751	-0.918	0.169	-0.904	4
5	2029.0	2047.7	-18.7	0.980	-1.198	4.714	-1.254	5
6	1733.0	1719.7	13.3	0.919	0.424	0.135	0.393	6
7	1835.0	1821.7	13.3	0.919	0.424	0.135	0.393	7
8	1549.0	1551.7	-2.7	0.986	-0.203	0.190	-0.186	8
9	1417.0	1435.7	-18.7	0.980	-1.198	4.714	-1.254	9
10	2060.0	1967.3	92.7	0.492	1.176	0.089	1.224	10
11	2060.0	2014.5	45.5	0.141	0.444	0.002	0.412	11
12	1835.0	1827.0	8.0	0.872	0.203	0.019	0.186	12
13	1917.0	1861.0	56.0	0.821	1.198	0.439	1.254	13
14	2090.0	2014.5	75.5	0.141	0.737	0.006	0.705	14
15	1866.0	1858.0	8.0	0.872	0.203	0.019	0.186	15
16	1825.0	1817.0	8.0	0.872	0.203	0.019	0.186	16
17	1937.0	2014.5	-77.5	0.141	-0.757	0.006	-0.726	17
18	2161.0	2153.0	8.0	0.872	0.203	0.019	0.186	18
19	1988.0	1932.0	56.0	0.821	1.198	0.439	1.254	19
20	1835.0	2014.5	-179.5	0.141	-1.752	0.034	-2.288	20
21	2070.0	2014.0	56.0	0.821	1.198	0.439	1.254	21

Table C2. 1/8" Aluminum Statistical Analysis of Cumulative Mass Loss

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	0.060966	1	0.060966		
Linear	0.000391	4	0.000098	1.049	0.4133
Quadratic	0.001002	10	0.000100	1.233	0.4156
Cubic	0.000462	2	0.000231	36.24	0.0027
RESIDUAL	0.000026	4	0.000006		
TOTAL	0.062847	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	0.001464	12	0.000122	19.14	0.0058
Quadratic	0.000462	2	0.000231	36.24	0.0027
Cubic	0.000000	0			
PURE ERR	0.000026	4	0.000006		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	0.00965	0.2077	0.0096	0.00310
Quadratic	15	6	0.00902	0.7406	0.1354	0.08582
Cubic	17	4	0.00253	0.9864	0.9322	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	0.001393	14	0.00010	1.224	0.4256
RESIDUAL	0.000488	6	0.00008		
Lack Of Fit	0.000462	2	0.00023	36.24	0.0027
Pure Error	0.000026	4	0.00001		
COR TOTAL	0.001880	20			

ROOT MSE	0.00902	R-SQUARED	0.7406
DEP MEAN	0.05388	ADJ R-SQUARED	0.1354
C.V.	16.73%		

Predicted Residual Sum of Squares (PRESS) = 0.085825

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	0.05521	1	0.00338	16.31	
A	0.00422	1	0.00534	0.7908	0.4592
B	0.00768	1	0.01673	0.4589	0.6625
C	-0.01055	1	0.00638	-1.655	0.1490
D	-0.00220	1	0.00638	-0.3451	0.7418

Table C2. 1/8" Aluminum Statistical Analysis of Cumulative Mass Loss

A2	0.00166	1	0.00535	0.3105	0.7667
B2	-0.00194	1	0.00914	-0.2123	0.8389
C2	0.01274	1	0.00519	2.453	0.0496
D2	-0.00152	1	0.00492	-0.3082	0.7684
AB	-0.00662	1	0.01222	-0.5418	0.6075
AC	-0.00027	1	0.01283	-2.12E-02	0.9838
AD	-0.01372	1	0.01387	-0.9896	0.3606
BC	0.00201	1	0.00599	0.3358	0.7485
BD	-0.00900	1	0.00929	-0.9683	0.3703
CD	0.01064	1	0.01374	0.7745	0.4680

Final Equation in Terms of Actual Factors:

```
CumMassLoss =
                  -0.39436
       +         5.298E-02 * Spray Dist
       +         5.600E-03 * Angle
       -         2.133E-03 * Current
       +         6.806E-03 * Pressure
       +         1.847E-04 * Spray Dist^2
       -         3.832E-06 * Angle      ^2
       +         1.274E-06 * Current^2
       -         1.517E-05 * Pressure^2
       -         9.809E-05 * Spray Dist * Angle
       -         9.060E-07 * Spray Dist * Current
       -         4.575E-04 * Spray Dist * Pressure
       +         8.937E-07 * Angle      * Current
       -         3.999E-05 * Angle      * Pressure
       +         1.064E-05 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	0.05030	0.05004	0.00026	0.980	0.208	0.141	0.190	1
2	0.05150	0.05265	-0.00115	0.492	-0.179	0.002	-0.163	2
3	0.05590	0.05337	0.00253	0.986	2.356	25.701	7.874	3
4	0.04660	0.05087	-0.00427	0.751	-0.949	0.181	-0.939	4
5	0.04770	0.04744	0.00026	0.980	0.208	0.141	0.190	5
6	0.06420	0.05940	0.00480	0.919	1.868	2.633	2.637	6
7	0.06280	0.05800	0.00480	0.919	1.868	2.633	2.637	7
8	0.05910	0.05657	0.00253	0.986	2.356	25.701	7.874	8
9	0.04790	0.04764	0.00026	0.980	0.208	0.141	0.190	9
10	0.05100	0.05265	-0.00165	0.492	-0.256	0.004	-0.235	10
11	0.06550	0.05521	0.01029	0.141	1.232	0.017	1.301	11
12	0.05350	0.06109	-0.00759	0.872	-2.356	2.527	-7.874	12
13	0.04480	0.04559	-0.00079	0.821	-0.208	0.013	-0.190	13
14	0.06060	0.05521	0.00539	0.141	0.645	0.005	0.611	14
15	0.02450	0.03209	-0.00759	0.872	-2.356	2.527	-7.874	15
16	0.07090	0.07849	-0.00759	0.872	-2.356	2.527	-7.874	16
17	0.06030	0.05521	0.00509	0.141	0.609	0.004	0.574	17
18	0.04980	0.05739	-0.00759	0.872	-2.356	2.527	-7.874	18
19	0.05510	0.05589	-0.00079	0.821	-0.208	0.013	-0.190	19
20	0.05880	0.05521	0.00359	0.141	0.430	0.002	0.399	20
21	0.05070	0.05149	-0.00079	0.821	-0.208	0.013	-0.190	21

Table C3. 1/8" Aluminum Statistical Analysis of Microhardness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	52620.07	1	52620.07		
Linear	1.51	4	0.38	0.1756	0.9477
Quadratic	26.12	10	2.61	1.900	0.2231
Cubic	0.46	2	0.23	0.1180	0.8916
RESIDUAL	7.79	4	1.95		
TOTAL	52655.94	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	26.58	12	2.21	1.138	0.4951
Quadratic	0.46	2	0.23	0.1180	0.8916
Cubic	0.00	0			
PURE ERR	7.79	4	1.95		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	1.465	0.0421	-0.1974	55.803
Quadratic	15	6	1.172	0.7701	0.2336	118.143
Cubic	17	4	1.395	0.7829	-0.0855	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	27.62	14	1.973	1.436	0.3432
RESIDUAL	8.25	6	1.375		
Lack Of Fit	0.46	2	0.230	0.1180	0.8916
Pure Error	7.79	4	1.947		
COR TOTAL	35.87	20			

ROOT MSE	1.172	R-SQUARED	0.7701
DEP MEAN	50.057	ADJ R-SQUARED	0.2336
C.V.	2.34%		

Predicted Residual Sum of Squares (PRESS) = 118.14

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	49.593	1	0.440	112.7	
A	-0.303	1	0.694	-0.4367	0.6776
B	4.762	1	2.176	2.189	0.0712
C	0.900	1	C33 0.829	1.086	0.3193

D2	1.435	1	0.640	2.243	0.0661
AB	-2.696	1	1.589	-1.696	0.1407
AC	0.041	1	1.668	2.44E-02	0.9814
AD	2.866	1	1.803	1.589	0.1632
BC	-0.176	1	0.779	-0.2261	0.8287
BD	-0.247	1	1.208	-0.2043	0.8449
CD	3.203	1	1.786	1.793	0.1232

Final Equation in Terms of Actual Factors:

```
Microhard =
                 369.820
   -              4.6430 * Spray Dist
   -             0.14415 * Angle
   -             0.42200 * Current
   -              4.6728 * Pressure
   -           8.129E-02 * Spray Dist^2
   +           4.735E-03 * Angle      ^2
   +           1.665E-04 * Current^2
   +           1.435E-02 * Pressure^2
   -           3.994E-02 * Spray Dist * Angle
   +           1.355E-04 * Spray Dist * Current
   +           9.552E-02 * Spray Dist * Pressure
   -           7.824E-05 * Angle        * Current
   -           1.097E-03 * Angle        * Pressure
   +           3.203E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	51.200	51.191	0.009	0.980	0.057	0.011	0.052	1
2	51.100	49.164	1.936	0.492	2.317	0.347	6.508	2
3	49.700	49.781	-0.081	0.986	-0.578	1.546	-0.543	3
4	49.900	49.710	0.190	0.751	0.324	0.021	0.298	4
5	49.600	49.591	0.009	0.980	0.057	0.011	0.052	5
6	49.900	50.071	-0.171	0.919	-0.511	0.197	-0.477	6
7	51.500	51.671	-0.171	0.919	-0.511	0.197	-0.477	7
8	51.100	51.181	-0.081	0.986	-0.578	1.546	-0.543	8
9	51.300	51.291	0.009	0.980	0.057	0.011	0.052	9
10	47.300	49.164	-1.864	0.492	-2.231	0.321	-4.935	10
11	49.200	49.593	-0.393	0.141	-0.361	0.001	-0.333	11
12	48.800	48.558	0.242	0.872	0.578	0.152	0.543	12
13	47.200	47.228	-0.028	0.821	-0.057	0.001	-0.052	13
14	49.000	49.593	-0.593	0.141	-0.545	0.003	-0.511	14
15	49.900	49.658	0.242	0.872	0.578	0.152	0.543	15
16	50.600	50.358	0.242	0.872	0.578	0.152	0.543	16
17	49.500	49.593	-0.093	0.141	-0.085	0.000	-0.078	17
18	52.400	52.158	0.242	0.872	0.578	0.152	0.543	18
19	50.200	50.228	-0.028	0.821	-0.057	0.001	-0.052	19
20	50.000	49.593	0.407	0.141	0.375	0.002	0.346	20
21	51.800	51.828	-0.028	0.821	-0.057	0.001	-0.052	21

Table C4. 1/8" Aluminum Statistical Analysis of Oxides

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	357.12	1	357.12		
Linear	3.28	4	0.82	0.4672	0.7590
Quadratic	19.24	10	1.92	1.311	0.3847
Cubic	0.62	2	0.31	0.1525	0.8633
RESIDUAL	8.18	4	2.05		
TOTAL	388.44	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	19.86	12	1.66	0.8094	0.6527
Quadratic	0.62	2	0.31	0.1525	0.8633
Cubic	0.00	0			
PURE ERR	8.18	4	2.05		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	1.324	0.1046	-0.1193	51.643
Quadratic	15	6	1.211	0.7189	0.0630	141.460
Cubic	17	4	1.430	0.7388	-0.3060	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	22.51	14	1.608	1.096	0.4859
RESIDUAL	8.80	6	1.467		
Lack Of Fit	0.62	2	0.312	0.1525	0.8633
Pure Error	8.18	4	2.045		
COR TOTAL	31.32	20			

ROOT MSE	1.211	R-SQUARED	0.7189
DEP MEAN	4.124	ADJ R-SQUARED	0.0630
C.V.	29.37%		

Predicted Residual Sum of Squares (PRESS) = 141.46

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	4.153	1	C35 0.455	9.132	
A	-0.591	1	0.718	-0.8230	0.4420
B	1.550	1	2.248	0.6895	0.5163
C	2.250	1	C35 0.857	2.627	0.0392

D2	0.716	1	0.661	1.082	0.3206
AB	-3.277	1	1.642	-1.996	0.0929
AC	-2.695	1	1.724	-1.564	0.1690
AD	5.092	1	1.863	2.733	0.0341
BC	0.699	1	0.805	0.8690	0.4182
BD	-1.491	1	1.248	-1.194	0.2775
CD	2.856	1	1.846	1.547	0.1728

Final Equation in Terms of Actual Factors:

```
Oxides =
                 205.321
      -           8.7646 * Spray Dist
      +          0.68053 * Angle
      -          0.16211 * Current
      -           3.3827 * Pressure
      -        4.955E-02 * Spray Dist^2
      +        2.105E-03 * Angle       ^2
      -        6.865E-05 * Current^2
      +        7.159E-03 * Pressure^2
      -        4.855E-02 * Spray Dist * Angle
      -        8.984E-03 * Spray Dist * Current
      +          0.16973 * Spray Dist * Pressure
      +        3.108E-04 * Angle        * Current
      -        6.624E-03 * Angle        * Pressure
      +        2.856E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	2.900	2.977	-0.077	0.980	-0.451	0.667	-0.419	1
2	4.200	4.298	-0.098	0.492	-0.113	0.001	-0.103	2
3	3.100	3.028	0.072	0.986	0.500	1.158	0.466	3
4	5.300	5.675	-0.375	0.751	-0.621	0.077	-0.586	4
5	3.700	3.777	-0.077	0.980	-0.451	0.667	-0.419	5
6	4.000	3.779	0.221	0.919	0.641	0.311	0.607	6
7	4.300	4.079	0.221	0.919	0.641	0.311	0.607	7
8	5.700	5.628	0.072	0.986	0.500	1.158	0.466	8
9	3.600	3.677	-0.077	0.980	-0.451	0.667	-0.419	9
10	4.400	4.298	0.102	0.492	0.119	0.001	0.108	10
11	2.800	4.153	-1.353	0.141	-1.205	0.016	-1.264	11
12	2.900	3.117	-0.217	0.872	-0.500	0.114	-0.466	12
13	3.900	3.669	0.231	0.821	0.451	0.062	0.419	13
14	5.200	4.153	1.047	0.141	0.933	0.010	0.921	14
15	5.100	5.317	-0.217	0.872	-0.500	0.114	-0.466	15
16	1.000	1.217	-0.217	0.872	-0.500	0.114	-0.466	16
17	2.800	4.153	-1.353	0.141	-1.205	0.016	-1.264	17
18	5.500	5.717	-0.217	0.872	-0.500	0.114	-0.466	18
19	5.300	5.069	0.231	0.821	0.451	0.062	0.419	19
20	6.000	4.153	1.847	0.141	1.645	0.030	2.027	20
21	4.900	4.669	0.231	0.821	0.451	0.062	0.419	21

Table C5. 1/8" Aluminum Statistical Analysis of Porosity

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	2102.0	1	2102.0		
Linear	168.1	4	42.0	3.210	0.0409
Quadratic	183.5	10	18.3	4.227	0.0456
Cubic	5.8	2	2.9	0.5765	0.6026
RESIDUAL	20.2	4	5.1		
TOTAL	2479.6	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	189.3	12	15.8	3.121	0.1411
Quadratic	5.8	2	2.9	0.5765	0.6026
Cubic	0.0	0			
PURE ERR	20.2	4	5.1		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	3.62	0.4452	0.3065	359.40
Quadratic	15	6	2.08	0.9310	0.7701	967.25
Cubic	17	4	2.25	0.9465	0.7323	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	351.6	14	25.11	5.786	0.0201
RESIDUAL	26.0	6	4.34		
Lack Of Fit	5.8	2	2.91	0.5765	0.6026
Pure Error	20.2	4	5.05		
COR TOTAL	377.6	20			

ROOT MSE	2.08	R-SQUARED	0.9310
DEP MEAN	10.00	ADJ R-SQUARED	0.7701
C.V.	20.82%		

Predicted Residual Sum of Squares (PRESS) = 967.3

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	6.20	1	0.78	7.921	
A	1.04	1	1.23	0.8448	0.4306
B	-15.15	1	3.87	-3.919	0.0078
C	-1.55	1	1.47	-1.052	0.3332

D2	-1.21	1	1.14	-1.065	0.3279
AB	1.09	1	2.82	0.3877	0.7116
AC	-2.03	1	2.96	-0.6842	0.5194
AD	-10.05	1	3.20	-3.137	0.0201
BC	3.14	1	1.38	2.268	0.0638
BD	-0.09	1	2.15	-4.24E-02	0.9676
CD	-4.73	1	3.17	-1.491	0.1865

Final Equation in Terms of Actual Factors:

Porosity =

```
          -527.90
+          23.342 * Spray Dist
+          1.3684 * Angle
+         0.30200 * Current
+          7.0265 * Pressure
+         0.63450 * Spray Dist^2
-       1.464E-02 * Angle      ^2
+       1.303E-04 * Current^2
-       1.211E-02 * Pressure^2
+       1.622E-02 * Spray Dist * Angle
-       6.761E-03 * Spray Dist * Current
-         0.33509 * Spray Dist * Pressure
+       1.395E-03 * Angle      * Current
-       4.045E-04 * Angle      * Pressure
-       4.734E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	8.90	8.62	0.28	0.980	0.947	2.946	0.937	1
2	9.40	10.86	-1.46	0.492	-0.986	0.063	-0.983	2
3	12.60	12.45	0.15	0.986	0.603	1.682	0.568	3
4	12.30	11.76	0.54	0.751	0.515	0.053	0.481	4
5	10.80	10.52	0.28	0.980	0.947	2.946	0.937	5
6	16.00	15.98	0.02	0.919	0.035	0.001	0.032	6
7	14.20	14.18	0.02	0.919	0.035	0.001	0.032	7
8	10.40	10.25	0.15	0.986	0.603	1.682	0.568	8
9	21.40	21.12	0.28	0.980	0.947	2.946	0.937	9
10	11.90	10.86	1.04	0.492	0.698	0.031	0.664	10
11	10.50	6.20	4.30	0.141	2.229	0.054	4.907	11
12	12.50	12.95	-0.45	0.872	-0.603	0.165	-0.568	12
13	13.10	13.93	-0.83	0.821	-0.947	0.274	-0.937	13
14	5.60	6.20	-0.60	0.141	-0.309	0.001	-0.284	14
15	6.40	6.85	-0.45	0.872	-0.603	0.165	-0.568	15
16	8.60	9.05	-0.45	0.872	-0.603	0.165	-0.568	16
17	6.20	6.20	0.00	0.141	0.002	0.000	0.002	17
18	5.50	5.95	-0.45	0.872	-0.603	0.165	-0.568	18
19	5.20	6.03	-0.83	0.821	-0.947	0.274	-0.937	19
20	5.50	6.20	-0.70	0.141	-0.360	0.001	-0.333	20
21	3.10	3.93	-0.83	0.821	-0.947	0.274	-0.937	21

Table C6. 1/8" Aluminum Statistical Analysis of Roughness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	7769.1	1	7769.1		
Linear	124.7	4	31.2	2.477	0.0859
Quadratic	167.2	10	16.7	2.937	0.1000
Cubic	12.0	2	6.0	1.089	0.4192
RESIDUAL	22.1	4	5.5		
TOTAL	8095.1	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	179.2	12	14.9	2.701	0.1746
Quadratic	12.0	2	6.0	1.089	0.4192
Cubic	0.0	0			
PURE ERR	22.1	4	5.5		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	3.55	0.3824	0.2280	379.82
Quadratic	15	6	2.39	0.8952	0.6508	2533.11
Cubic	17	4	2.35	0.9322	0.6608	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	291.9	14	20.85	3.662	0.0595
RESIDUAL	34.2	6	5.69		
Lack Of Fit	12.0	2	6.02	1.089	0.4192
Pure Error	22.1	4	5.53		
COR TOTAL	326.0	20			

ROOT MSE	2.39	R-SQUARED	0.8952
DEP MEAN	19.23	ADJ R-SQUARED	0.6508
C.V.	12.40%		

Predicted Residual Sum of Squares (PRESS) = 2533.1

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	16.68	1	0.90	18.62	
A	0.31	1	1.41	0.2206	0.8327
B	-8.13	1	4.43	-1.836	0.1160
C	3.19	1	1.69	1.894	0.1071

D2	-1.57	1	1.30	-1.207	0.2729
AB	-4.18	1	3.23	-1.291	0.2442
AC	-10.37	1	3.40	-3.055	0.0224
AD	-0.61	1	3.67	-0.1661	0.8735
BC	4.13	1	1.58	2.603	0.0405
BD	-0.46	1	2.46	-0.1890	0.8563
CD	8.93	1	3.64	2.455	0.0494

Final Equation in Terms of Actual Factors:

```
     Ra Rough.   =
                         73.68
            +            17.903 * Spray Dist
            +            1.2417 * Angle
            -            1.1029 * Current
            -           0.29200 * Pressure
            +           0.10558 * Spray Dist^2
            -         8.231E-03 * Angle       ^2
            +         5.547E-04 * Current^2
            -         1.572E-02 * Pressure^2
            -         6.186E-02 * Spray Dist * Angle
            -         3.457E-02 * Spray Dist * Current
            -         2.033E-02 * Spray Dist * Pressure
            +         1.834E-03 * Angle        * Current
            -         2.065E-03 * Angle        * Pressure
            +         8.927E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	20.23	20.46	-0.23	0.980	-0.680	1.518	-0.646	1
2	16.31	17.32	-1.01	0.492	-0.594	0.023	-0.559	2
3	27.73	27.35	0.38	0.986	1.328	8.167	1.443	3
4	17.13	18.57	-1.44	0.751	-1.210	0.294	-1.270	4
5	15.66	15.89	-0.23	0.980	-0.680	1.518	-0.646	5
6	27.86	26.88	0.98	0.919	1.447	1.581	1.638	6
7	21.31	20.33	0.98	0.919	1.447	1.581	1.638	7
8	18.97	18.59	0.38	0.986	1.328	8.167	1.443	8
9	24.73	24.96	-0.23	0.980	-0.680	1.518	-0.646	9
10	18.18	17.32	0.86	0.492	0.506	0.017	0.472	10
11	18.29	16.68	1.61	0.141	0.728	0.006	0.696	11
12	16.81	17.94	-1.13	0.872	-1.328	0.803	-1.443	12
13	21.33	20.64	0.69	0.821	0.680	0.141	0.646	13
14	14.70	16.68	-1.98	0.141	-0.896	0.009	-0.879	14
15	15.14	16.27	-1.13	0.872	-1.328	0.803	-1.443	15
16	17.90	19.03	-1.13	0.872	-1.328	0.803	-1.443	16
17	20.33	16.68	3.65	0.141	1.650	0.030	2.038	17
18	24.29	25.42	-1.13	0.872	-1.328	0.803	-1.443	18
19	16.76	16.07	0.69	0.821	0.680	0.141	0.646	19
20	15.43	16.68	-1.25	0.141	-0.566	0.004	-0.531	20
21	14.83	14.14	0.69	0.821	0.680	0.141	0.646	21

Table C7. Minitab Analysis for 1/8" Aluminum

```
MTB > regress c6 10 c1-c5 c12-c16;
SUBC> residuals c22.
```

The regression equation is

CML = 12.7 +0.000026 BS - 0.00528 R + 0.00150 P + 0.00448 O - 0.126 MH
- 3 1/BS - 2.61 1/R + 0.091 1/P + 0.0433 1/O - 311 1/MH

Predictor	Coef	Stdev	t-ratio	p
Constant	12.731	8.032	1.59	0.144
BS	0.0000257	0.0001161	0.22	0.829
R	-0.005279	0.004642	-1.14	0.282
P	0.001495	0.001840	0.81	0.435
O	0.004482	0.004560	0.98	0.349
MH	-0.12614	0.08047	-1.57	0.148
1/BS	-2.8	376.9	-0.01	0.994
1/R	-2.609	1.988	-1.31	0.219
1/P	0.0908	0.1095	0.83	0.426
1/O	0.04333	0.02853	1.52	0.160
1/MH	-311.4	198.0	-1.57	0.147

s = 0.01055 R-sq = 40.8% R-sq(adj) = 0.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	10	0.0007673	0.0000767	0.69	0.716
Error	10	0.0011132	0.0001113		
Total	20	0.0018804			

SOURCE	DF	SEQ SS
BS	1	0.0000000
R	1	0.0000769
P	1	0.0000083
O	1	0.0002237
MH	1	0.0000089
1/BS	1	0.0000016
1/R	1	0.0000165
1/P	1	0.0000002
1/O	1	0.0001557
1/MH	1	0.0002753

RESIDUALS:

0.0000223	0.0053400	-0.0018553	-0.0104050	-0.0036830	0.0067017
0.0061236	0.0092403	-0.0055346	0.0020258	0.0042877	0.0028960
-0.0037406	0.0112333	-0.0217538	-0.0004155	-0.0012916	-0.0054060
-0.0040006	0.0080586	0.0021567			

Appendix D. Results for the 3/16" Aluminum Wire System

Figures D1-D21: Photomicrographs D1-D21
Figures D22-D27: Perturbation Plots
Tables D1-D6: Design Expert Analysis
Table D7: Minitab Analysis

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PHOTO 1 TAKEN AT 200X

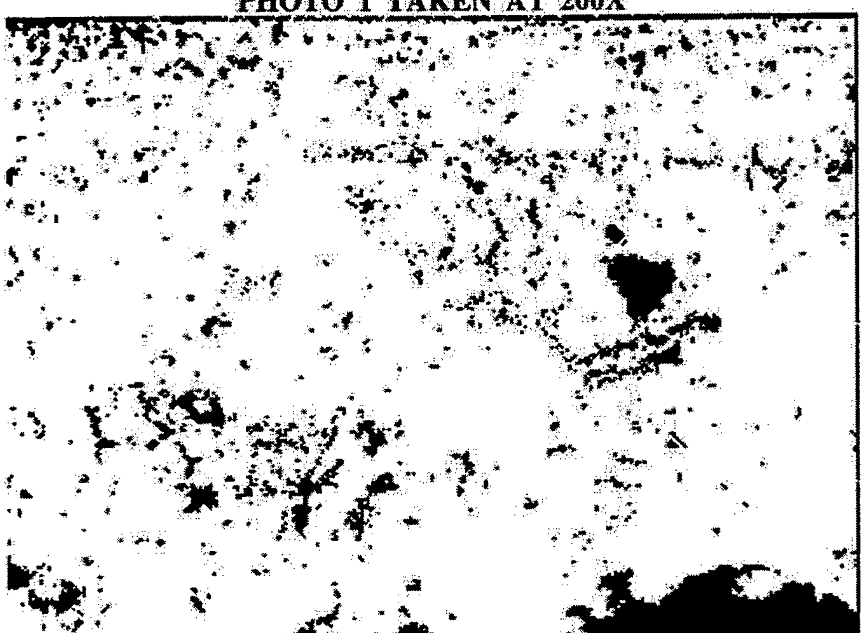

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA1

Figure D1. Photomicrograph of Coating BA1 (3/16" aluminum)

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PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA2

Figure D2. Photomicrograph of Coating BA2 (3/16" aluminum)

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PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA3

Figure D3. Photomicrograph of Coating BA3 (3/16" aluminum)

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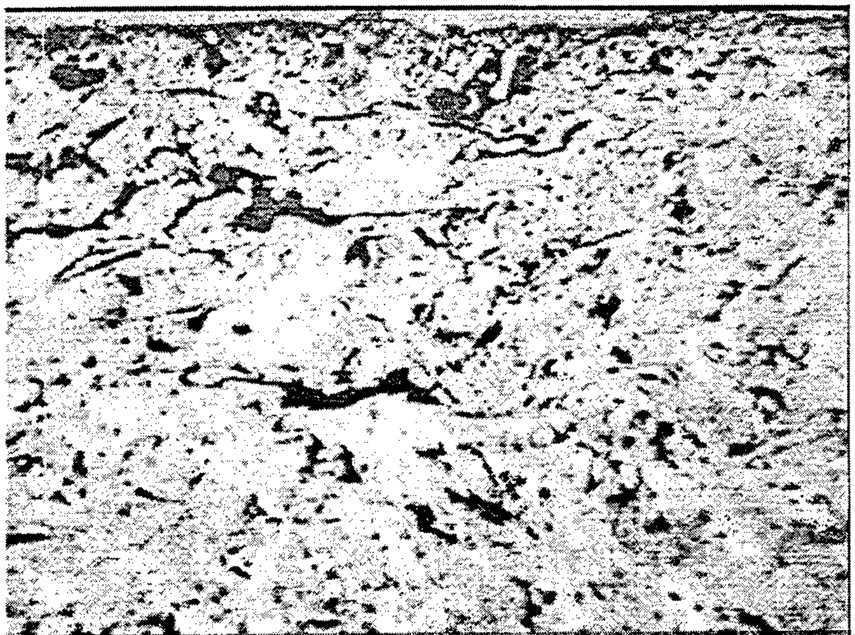

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA4

Figure D4. Photomicrograph of Coating BA4 (3/16" aluminum)

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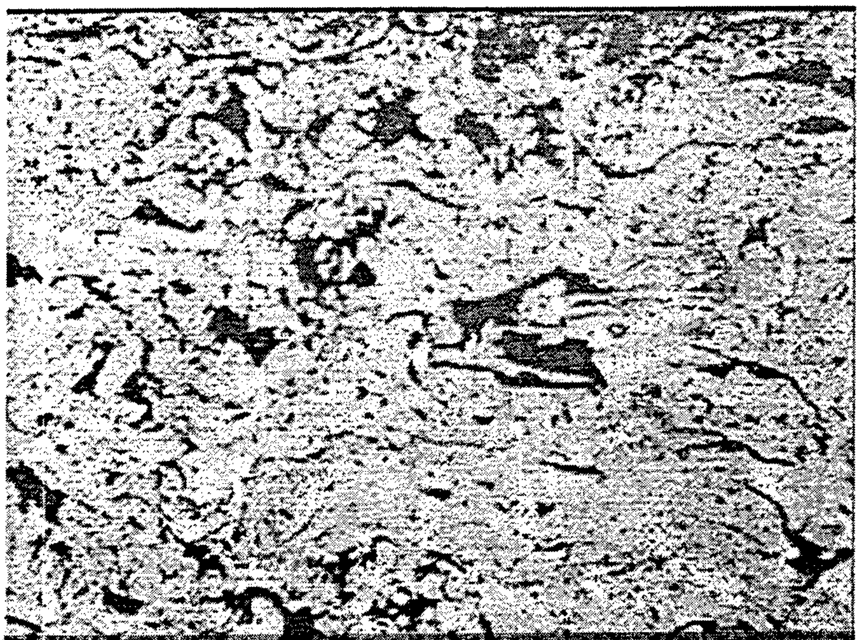

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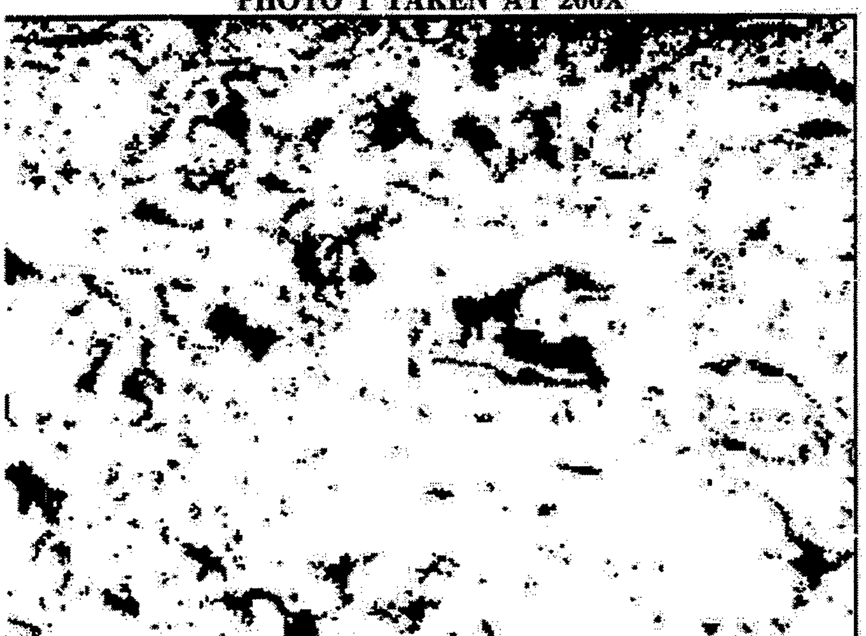

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA5

Figure D5. Photomicrograph of Coating BA5 (3/16" aluminum)

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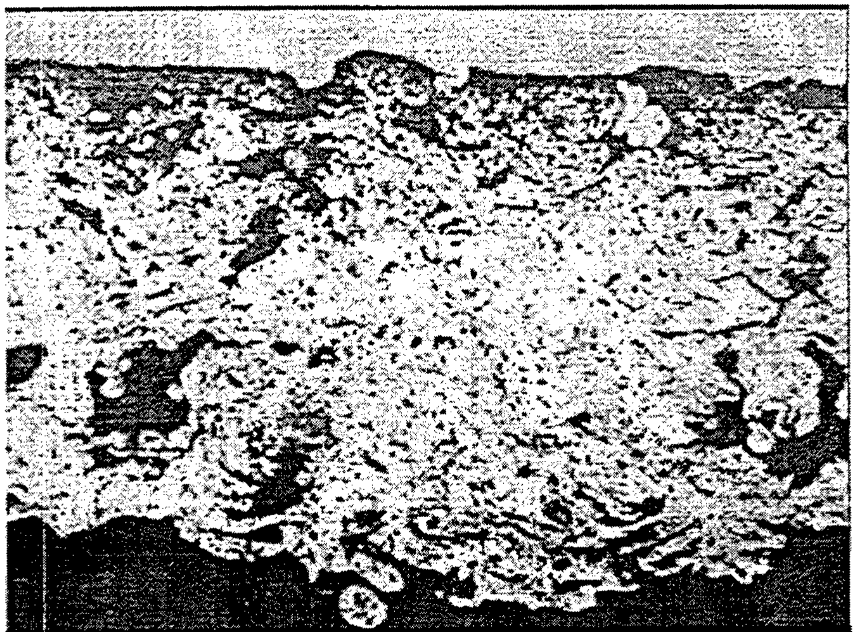

PHOTO 1 TAKEN AT 200X

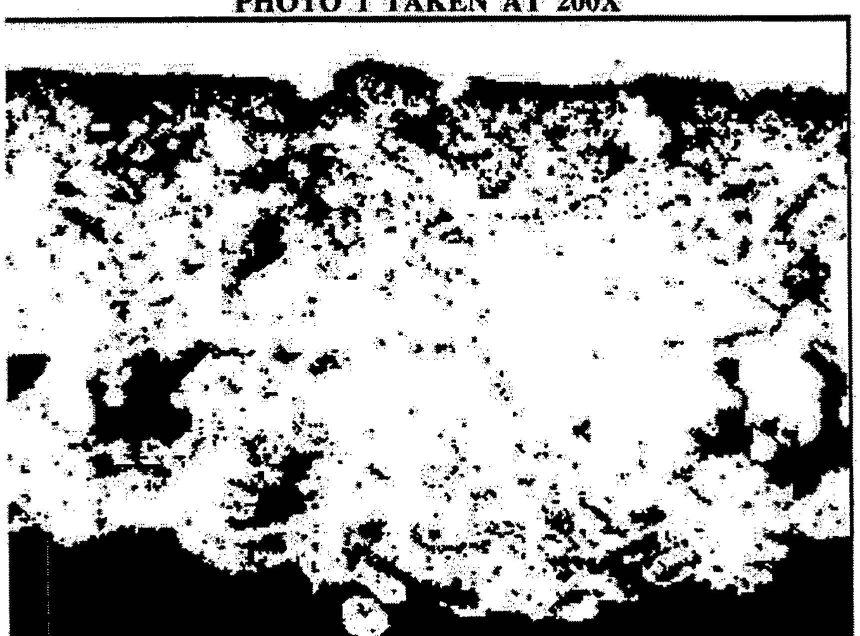

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA6

Figure D6. Photomicrograph of Coating BA6 (3/16" aluminum)

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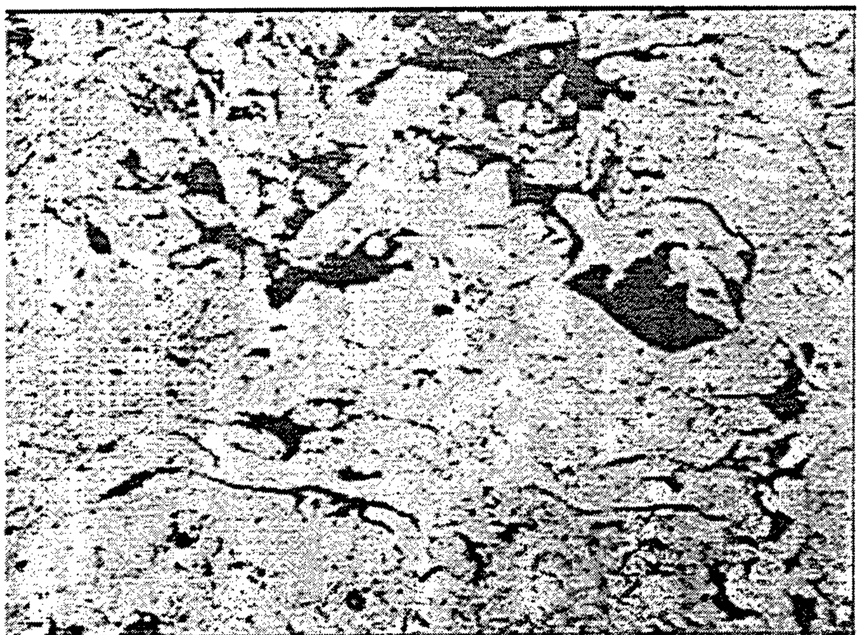

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA7

Figure D7. Photomicrograph of Coating BA7 (3/16" aluminum)

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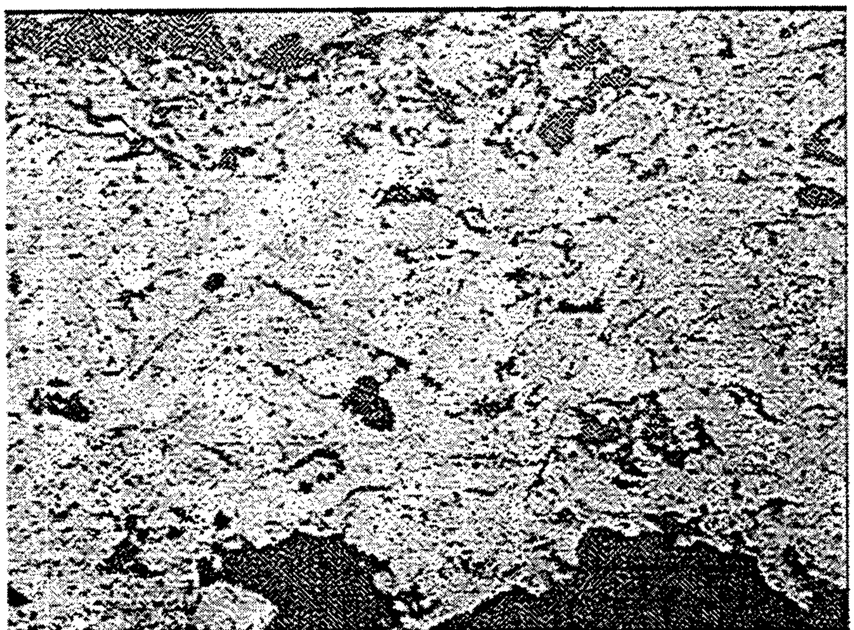

PHOTO 1 TAKEN AT 200X

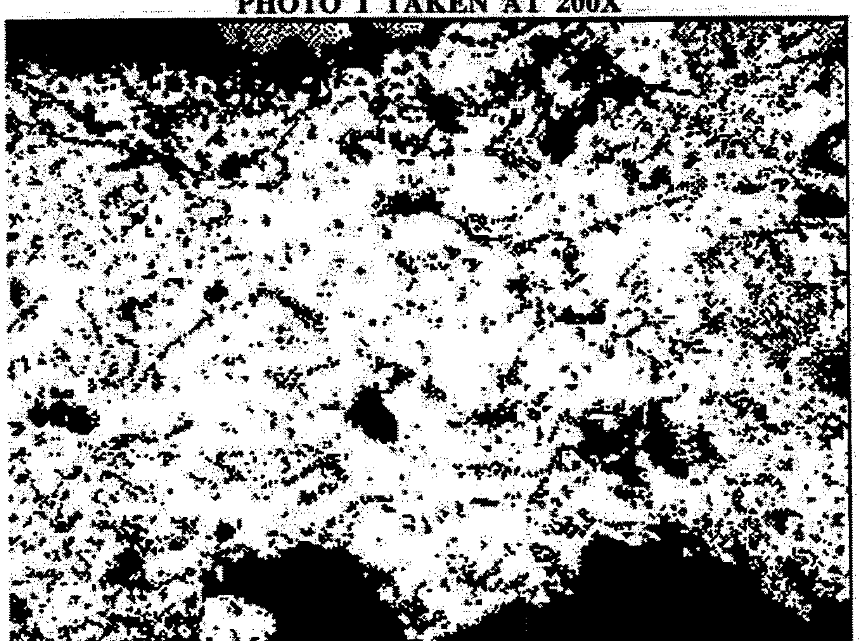

Figure D[illegible] Photomicrograph [illegible]uminum)

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA8

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PHOTO 1 TAKEN AT 200X

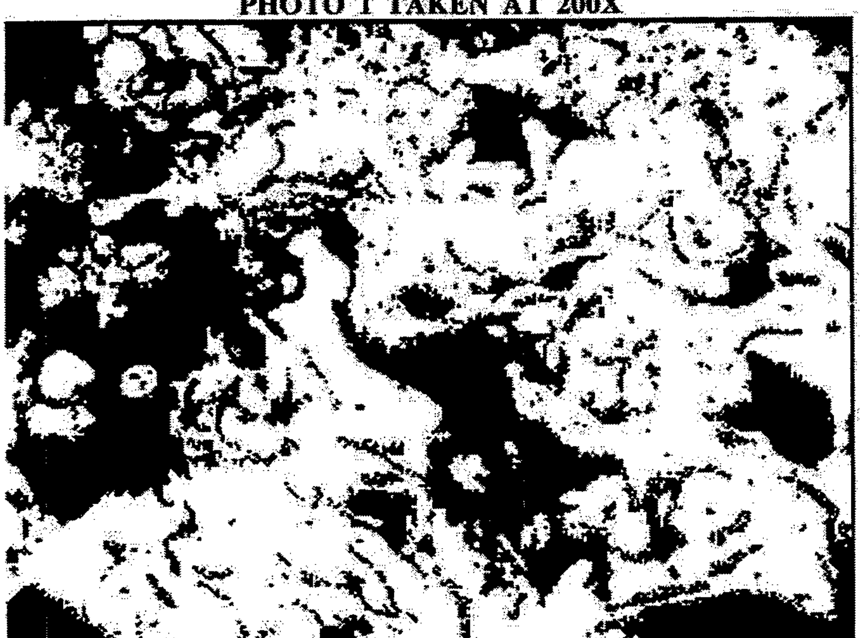

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA9

Figure D9. Photomicrograph of Coating BA9 (3/16" aluminum)

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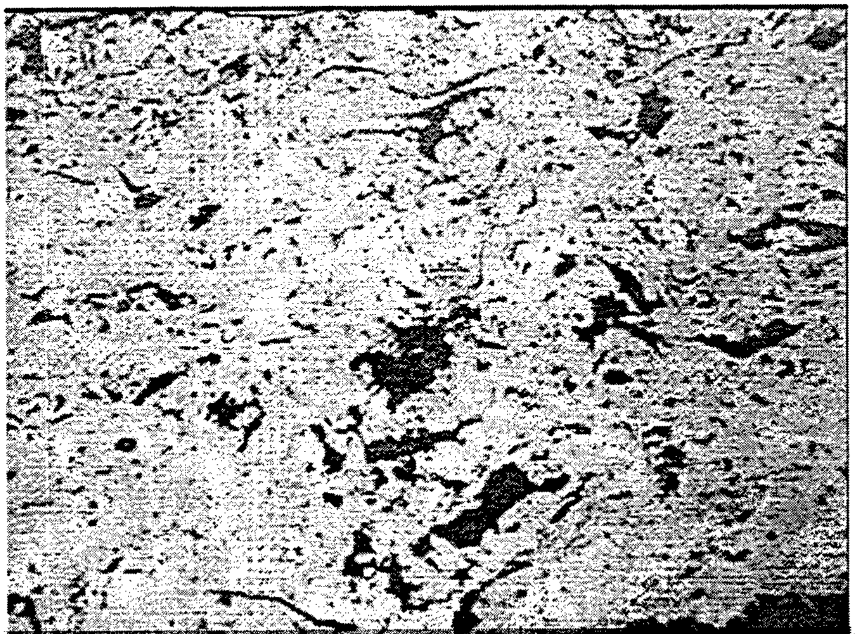

PHOTO 1 TAKEN AT 200X

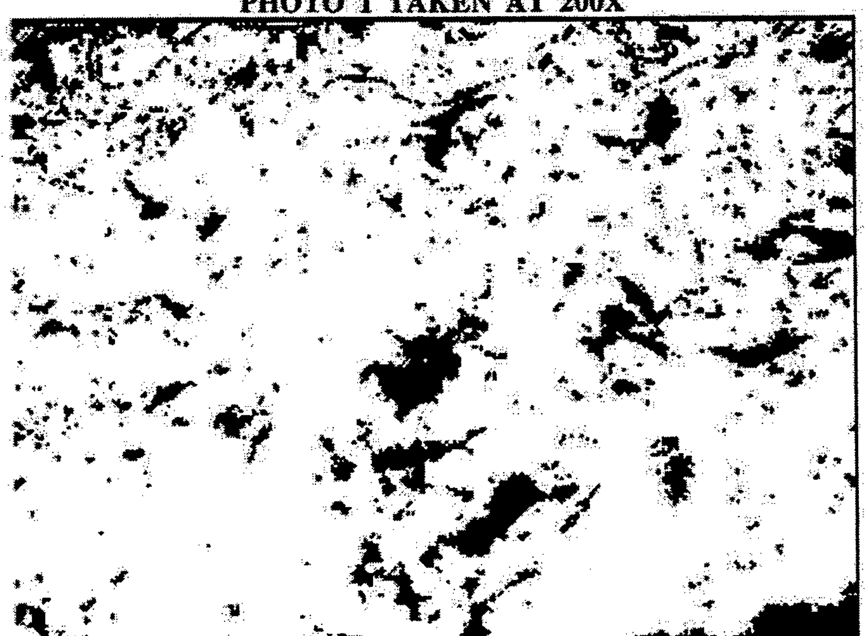

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA10

Figure D10. Photomicrograph of Coating BA10 (3/16" aluminum)

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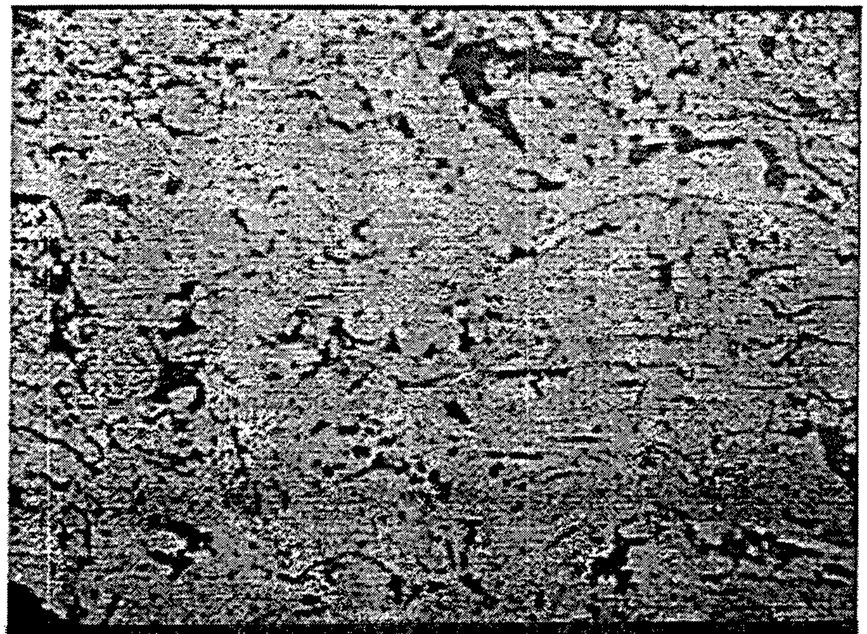

PHOTO 1 TAKEN AT 200X

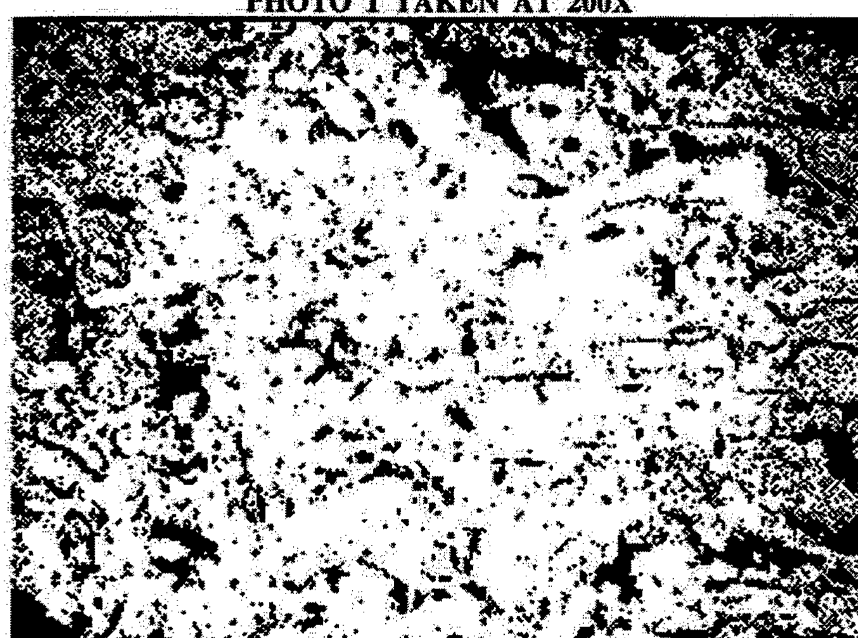

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA11

Figure D11. Photomicrograph of Coating BA11 (3/16" aluminum)

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PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA12

Figure D12. Photomicrograph of Coating BA12 (3/16" aluminum)

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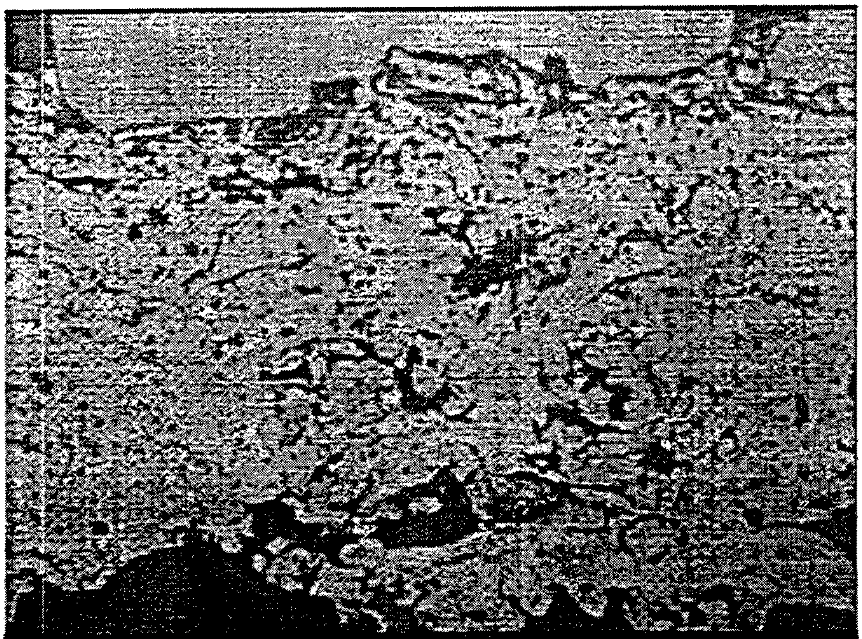

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA13

Figure D13. Photomicrograph of Coating BA13 (3/16" aluminum)

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PHOTO 1 TAKEN AT 200X

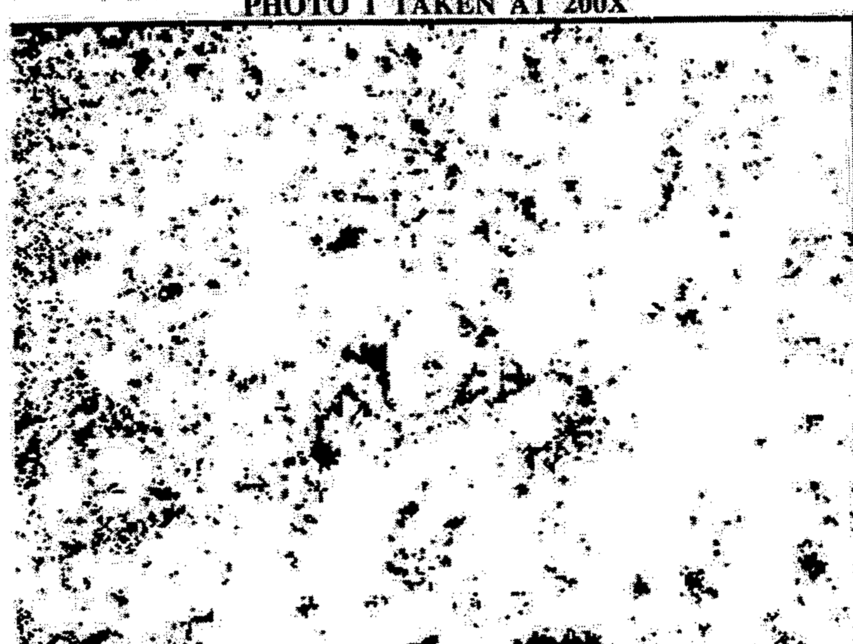

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA14

Figure D14. Photomicrograph of Coating BA14 (3/16" aluminum)

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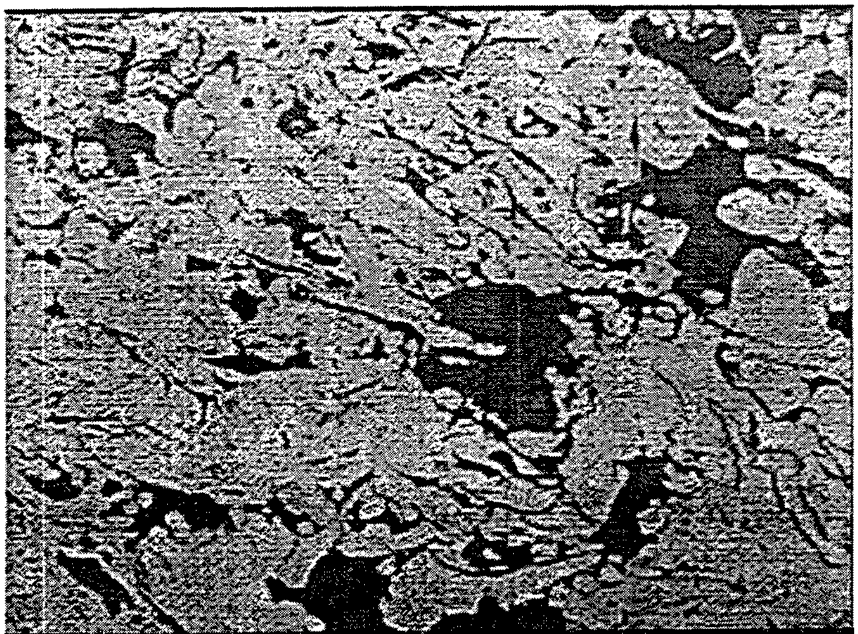

PHOTO 1 TAKEN AT 200X

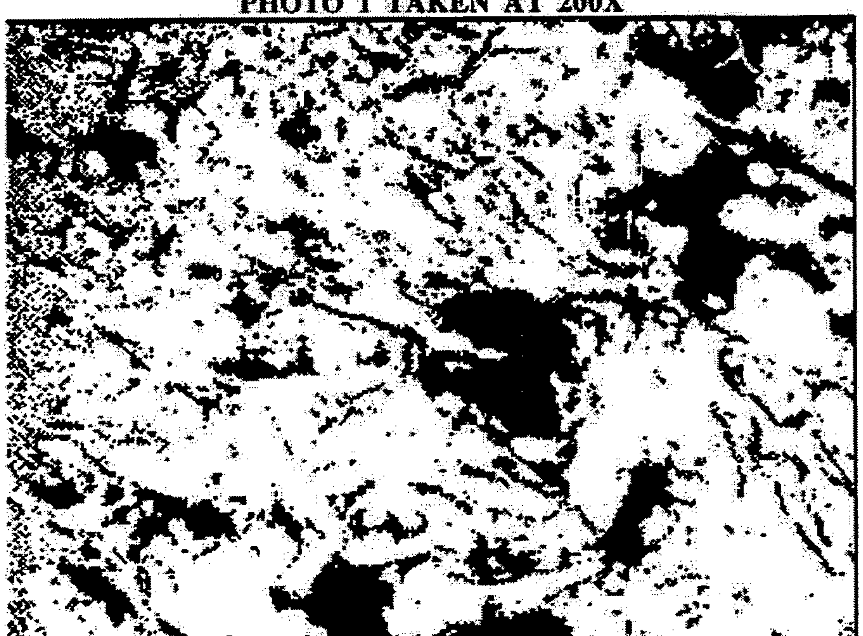

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA15

Figure D15. Photomicrograph of Coating BA15 (3/16" aluminum)

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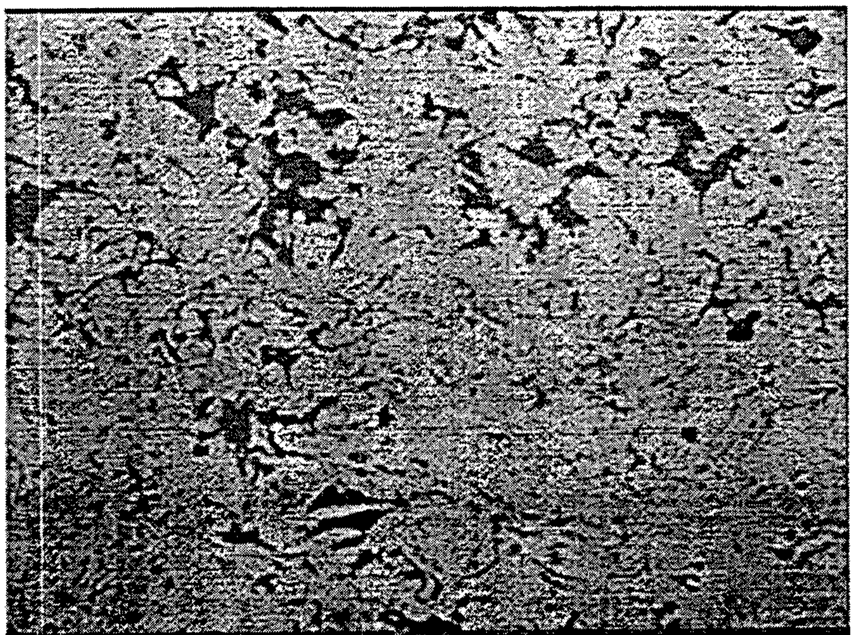

PHOTO 1 TAKEN AT 200X

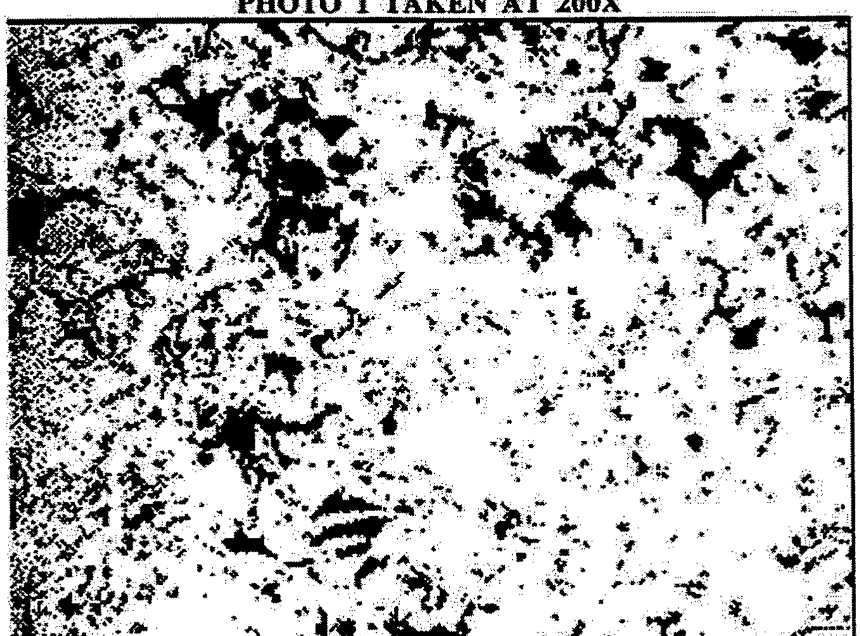

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA16

Figure D16. Photomicrograph of Coating BA16 (3/16" aluminum)

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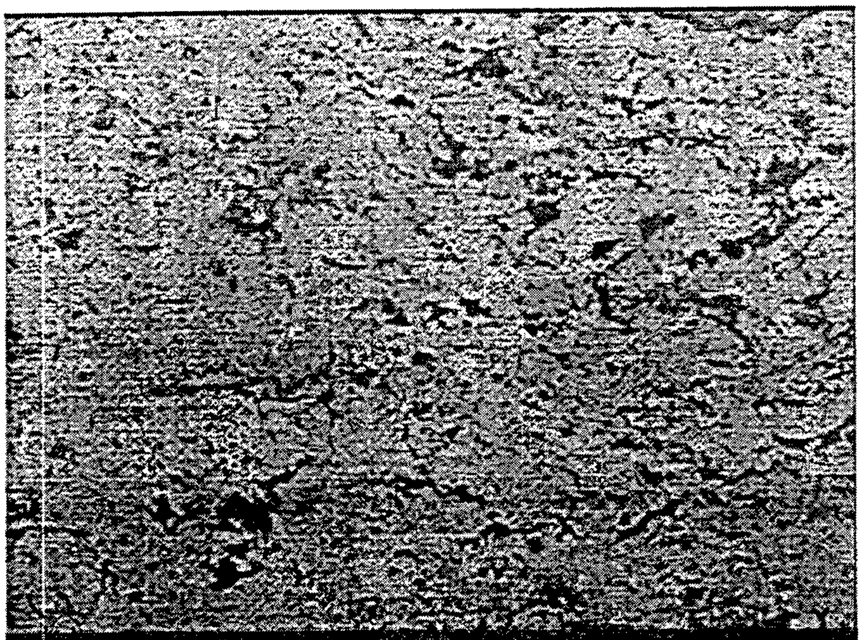

PHOTO 1 TAKEN AT 200X

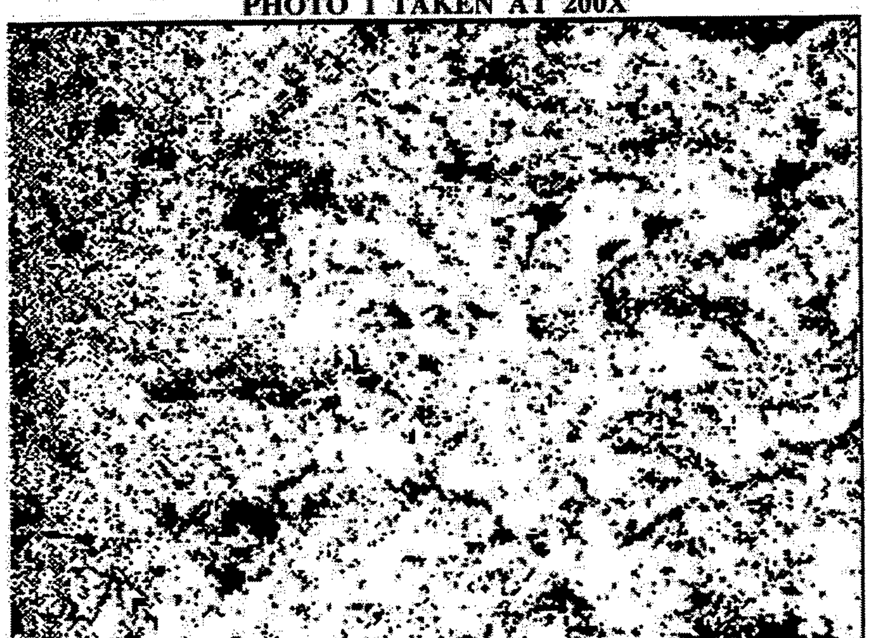

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA17

Figure D17. Photomicrograph of Coating BA17 (3/16" aluminum)

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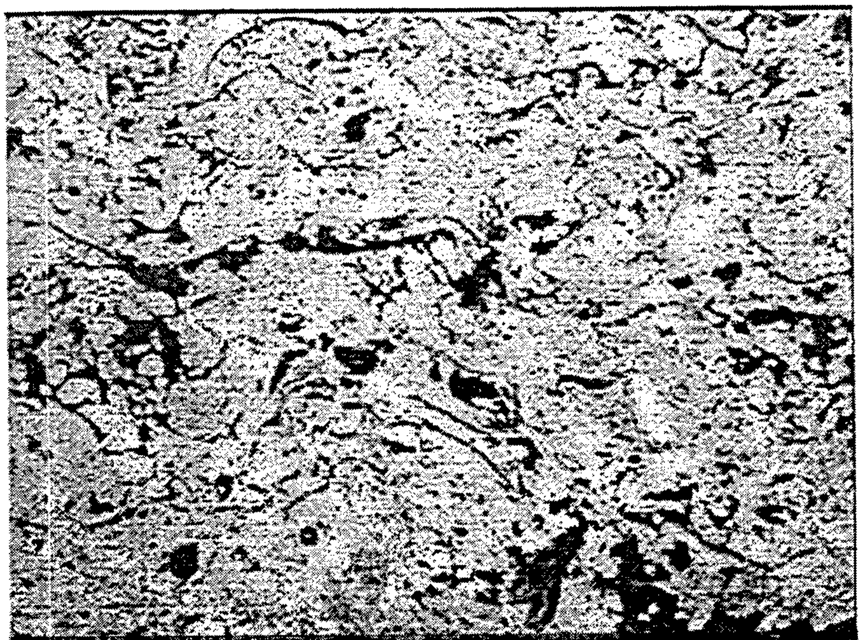

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA18

Figure D18. Photomicrograph of Coating BA18 (3/16" aluminum)

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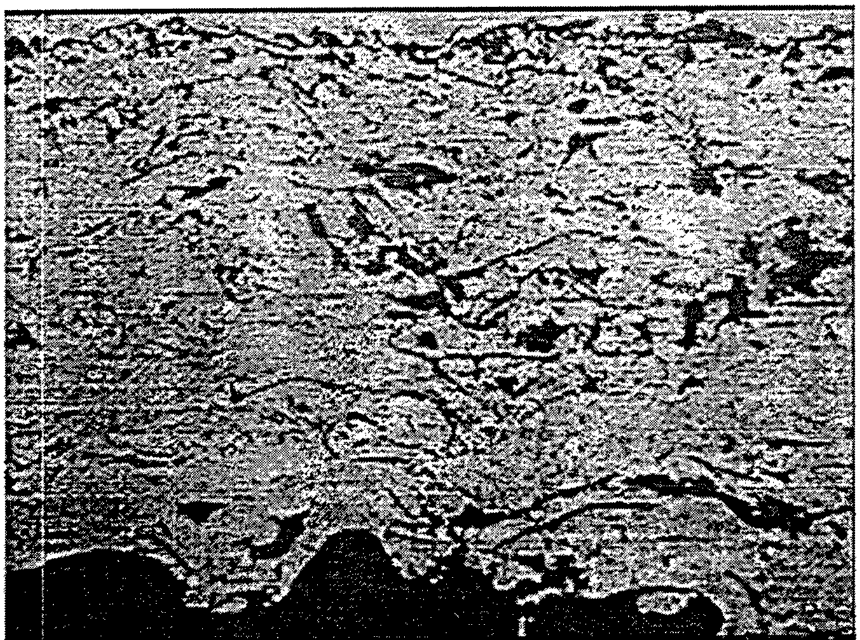

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA19

Figure D19. Photomicrograph of Coating BA19 (3/16" aluminum)

PROTECH LAB CORP.

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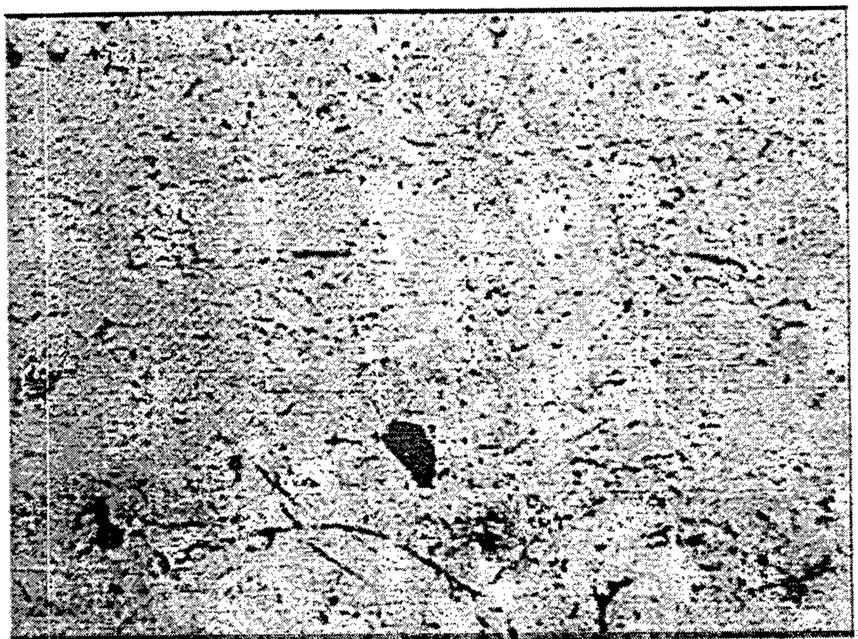

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA20

Figure D20. Photomicrograph of Coating BA20 (3/16" aluminum)

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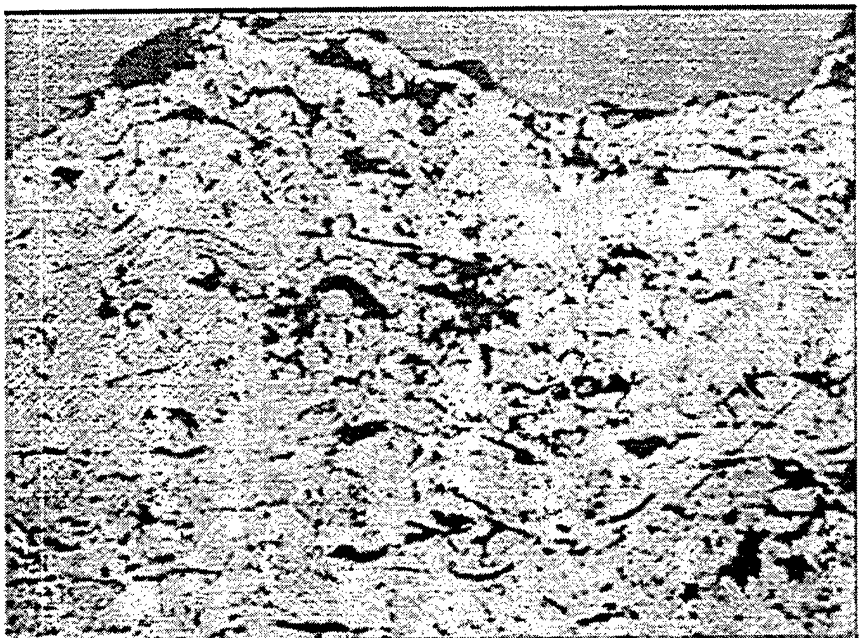

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-BA21

Figure D21. Photomicrograph of Coating BA21 (3/16" aluminum)

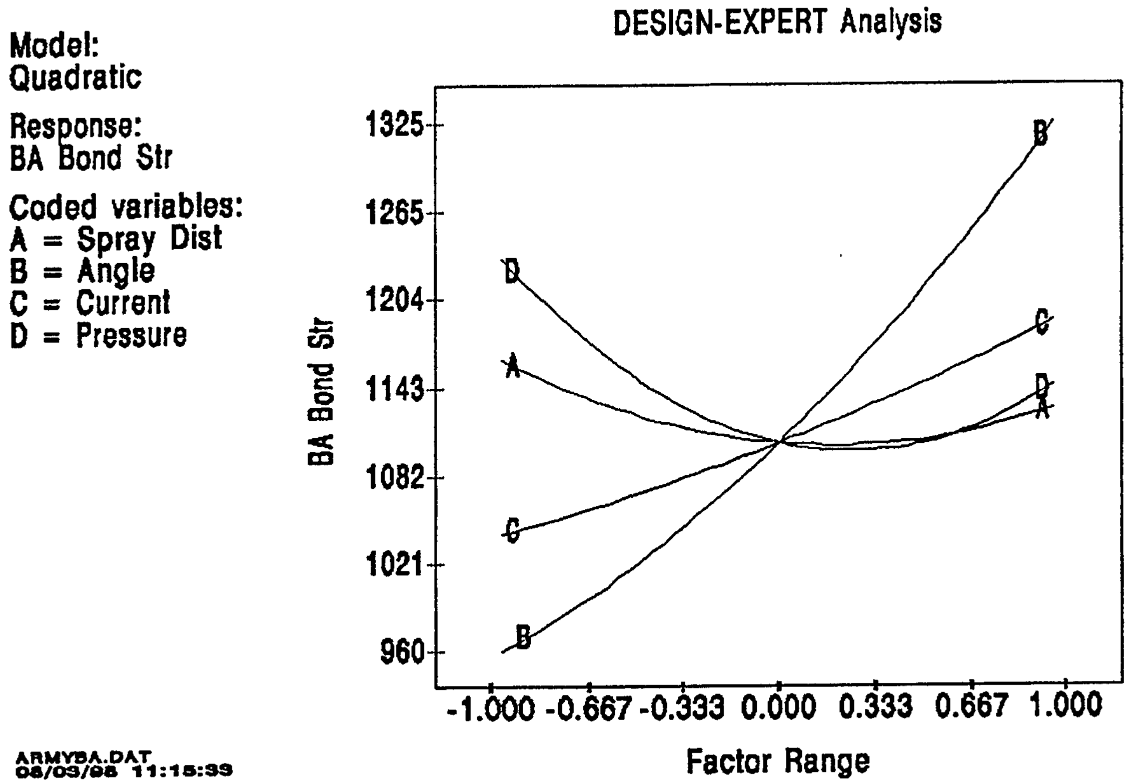

Figure D22. Bond Strength Parameter Plot for 3/16" Al Coatings

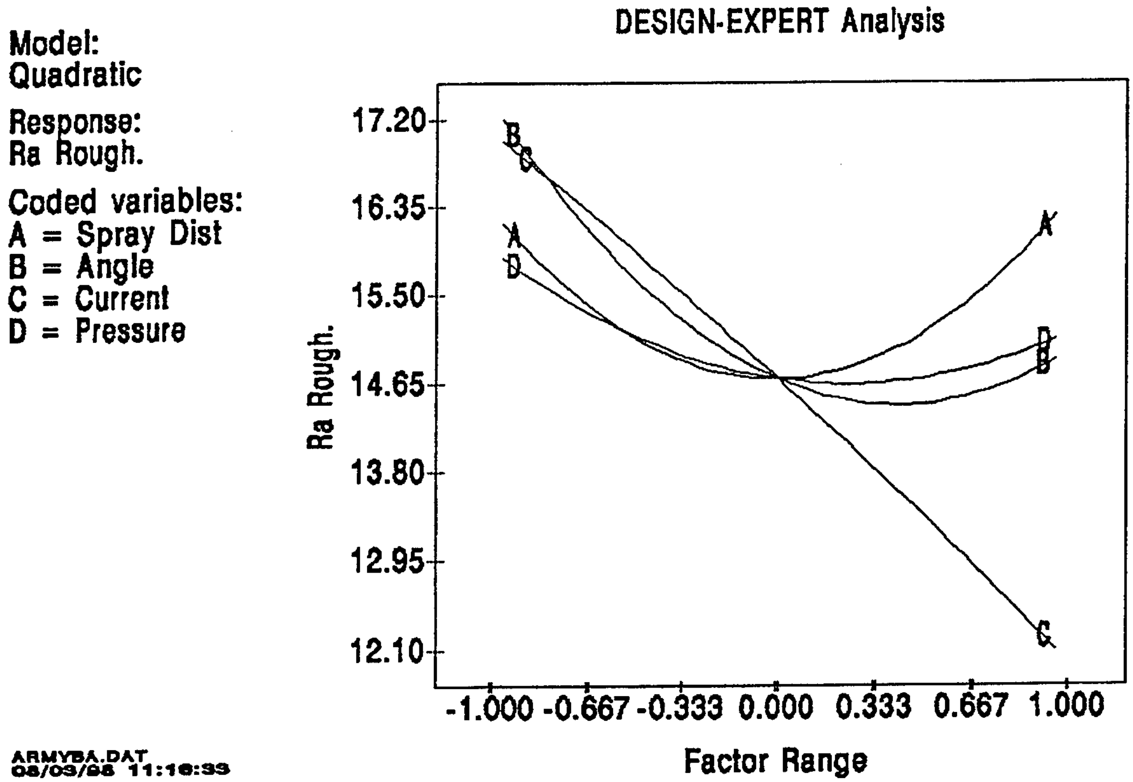

Figure D23. Roughness Parameter Plot for 3/16" Al Coatings

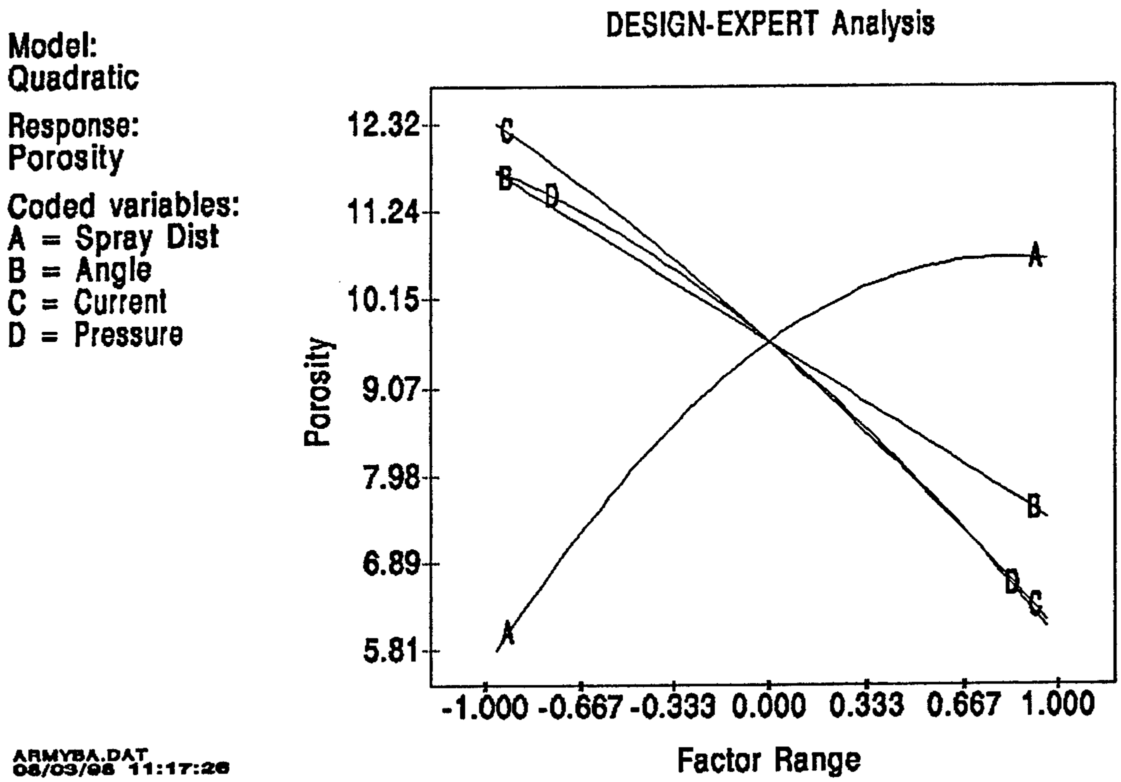

Figure D24. Porosity Parameter Plot for 3/16" Al Coatings

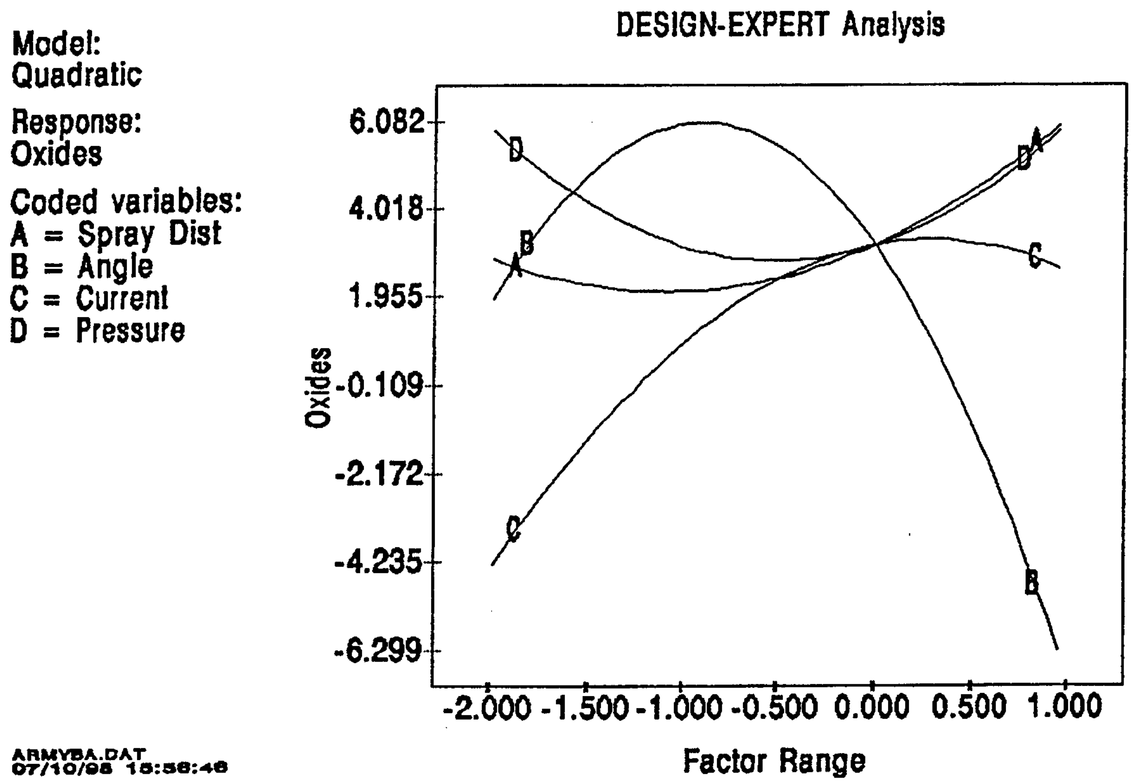

Figure D25. Oxides Parameter Plot for 3/16" Al Coatings

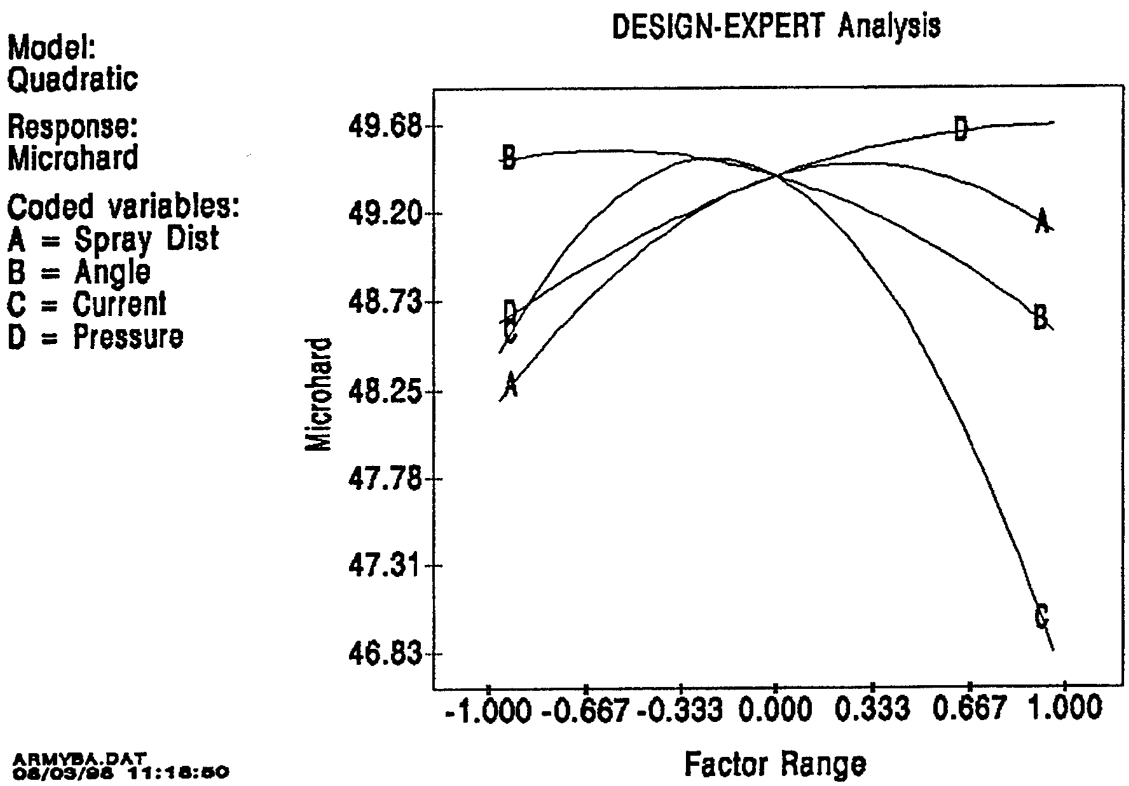

Figure D26. Hardness Parameter Plot for 3/16" Al Coatings

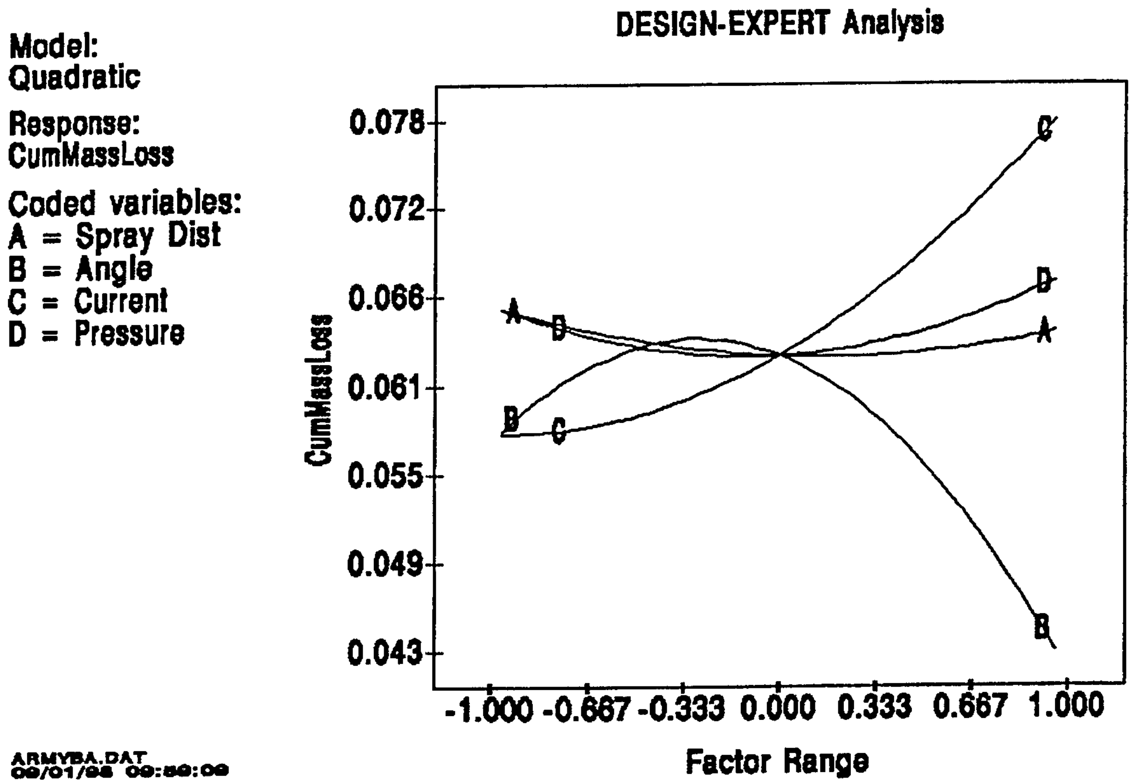

Figure D27. CML Parameter Plot for 3/16" Al Coatings

Table D1. 3/16" Aluminum Statistical Analysis of Bond Strength

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	24980629.3	1	24980629.3		
Linear	252219.7	4	63054.9	5.119	0.0075
Quadratic	154125.5	10	15412.6	2.153	0.1802
Cubic	8852.9	2	4426.5	0.5192	0.6303
RESIDUAL	34100.5	4	8525.1		
TOTAL	25429928.0	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	162978.4	12	13581.5	1.593	0.3481
Quadratic	8852.9	2	4426.5	0.5192	0.6303
Cubic	0.0	0			
PURE ERR	34100.5	4	8525.1		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	111.0	0.5614	0.4517	455547.8
Quadratic	15	6	84.6	0.9044	0.6813	1798646.4
Cubic	17	4	92.3	0.9241	0.6205	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	406345.3	14	29024.7	4.054	0.0473
RESIDUAL	42953.4	6	7158.9		
Lack Of Fit	8852.9	2	4426.5	0.5192	0.6303
Pure Error	34100.5	4	8525.1		
COR TOTAL	449298.7	20			

ROOT MSE	84.6	R-SQUARED	0.9044
DEP MEAN	1090.7	ADJ R-SQUARED	0.6813
C.V.	7.76%		

Predicted Residual Sum of Squares (PRESS) = 1798646.4

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	1105.4	1	31.8	34.80	
A	-17.3	1	50.1	-0.3452	0.7417
B	190.1	1	157.0	1.211	0.2715
C	76.5	1	59.8	1.279	0.2482
D	-45.5	1	59.8	-0.7605	0.4758

AB	144.0	1	114.7	1.256	0.2559
AC	6.5	1	120.4	5.40E-02	0.9587
AD	-16.0	1	130.2	-0.1226	0.9064
BC	77.4	1	56.2	1.376	0.2178
BD	-3.4	1	87.2	-3.94E-02	0.9699
CD	-14.6	1	128.9	-0.1131	0.9137

Final Equation in Terms of Actual Factors:

BA Bond Str =

```
                 12524.5
        -         239.76 * Spray Dist
        -         35.720 * Angle
        -         1.8363 * Current
        -         173.44 * Pressure
        +         4.8657 * Spray Dist^2
        +      8.033E-02 * Angle      ^2
        +      1.099E-03 * Current^2
        +        0.90076 * Pressure^2
        +         2.1334 * Spray Dist * Angle
        +      2.169E-02 * Spray Dist * Current
        -        0.53182 * Spray Dist * Pressure
        +      3.438E-02 * Angle      * Current
        -      1.525E-02 * Angle      * Pressure
        -      1.458E-02 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	1294.0	1281.0	13.0	0.980	1.088	3.889	1.109	1
2	1039.0	1166.5	-127.5	0.492	-2.114	0.289	-3.819	2
3	1213.0	1216.0	-3.0	0.986	-0.302	0.422	-0.278	3
4	1049.0	1004.0	45.0	0.751	1.066	0.228	1.081	4
5	1356.0	1343.0	13.0	0.980	1.088	3.889	1.109	5
6	958.0	977.1	-19.1	0.919	-0.791	0.472	-0.763	6
7	836.0	855.1	-19.1	0.919	-0.791	0.472	-0.763	7
8	1100.0	1103.0	-3.0	0.986	-0.302	0.422	-0.278	8
9	784.0	771.0	13.0	0.980	1.088	3.889	1.109	9
10	1284.0	1166.5	117.5	0.492	1.949	0.245	2.937	10
11	1172.0	1105.4	66.6	0.141	0.850	0.008	0.827	11
12	1141.0	1131.9	9.1	0.872	0.302	0.042	0.278	12
13	917.0	956.0	-39.0	0.821	-1.088	0.362	-1.109	13
14	1110.0	1105.4	4.6	0.141	0.059	0.000	0.054	14
15	897.0	887.9	9.1	0.872	0.302	0.042	0.278	15
16	1049.0	1039.9	9.1	0.872	0.302	0.042	0.278	16
17	1100.0	1105.4	-5.4	0.141	-0.069	0.000	-0.063	17
18	1202.0	1192.9	9.1	0.872	0.302	0.042	0.278	18
19	1202.0	1241.0	-39.0	0.821	-1.088	0.362	-1.109	19
20	1090.0	1105.4	-15.4	0.141	-0.196	0.000	-0.180	20
21	1111.0	1150.0	-39.0	0.821	-1.088	0.362	-1.109	21

Table D2. 3/16" Aluminum Statistical Analysis of Cumulative Mass Loss

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	0.073538	1	0.073538		
Linear	0.002500	4	0.000625	2.920	0.0545
Quadratic	0.002092	10	0.000209	0.9417	0.5563
Cubic	0.000987	2	0.000493	5.706	0.0674
RESIDUAL	0.000346	4	0.000086		
TOTAL	0.079463	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	0.003078	12	0.000257	2.967	0.1522
Quadratic	0.000987	2	0.000493	5.706	0.0674
Cubic	0.000000	0			
PURE ERR	0.000346	4	0.000086		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	0.01463	0.4220	0.2775	0.00669
Quadratic	15	6	0.01490	0.7751	0.2502	0.20695
Cubic	17	4	0.00930	0.9416	0.7081	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	0.004592	14	0.00033	1.477	0.3294
RESIDUAL	0.001333	6	0.00022		
Lack Of Fit	0.000987	2	0.00049	5.706	0.0674
Pure Error	0.000346	4	0.00009		
COR TOTAL	0.005924	20			

ROOT MSE	0.01490	R-SQUARED	0.7751
DEP MEAN	0.05918	ADJ R-SQUARED	0.2502
C.V.	25.18%		

Predicted Residual Sum of Squares (PRESS) = 0.206951

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	0.06274	1	0.00560	11.21	
A	-0.00080	1	0.00883	-9.04E-02	0.9309
B	-0.00750	1	0.02766	-0.2712	0.7953
C	0.01060	1	0.01054	1.006	0.3533
D	0.00095	1	0.01054	9.01E-02	0.9311

Table D2. 3/16" Aluminum Statistical Analysis of Cumulative Mass Loss

A2	0.00243	1	0.00885	0.2745	0.7929
B2	-0.01312	1	0.01511	-0.8683	0.4186
C2	0.00553	1	0.00858	0.6445	0.5431
D2	0.00423	1	0.00814	0.5203	0.6215
AB	-0.00724	1	0.02020	-0.3583	0.7324
AC	-0.00963	1	0.02121	-0.4540	0.6658
AD	0.00146	1	0.02292	6.36E-02	0.9513
BC	0.02273	1	0.00990	2.296	0.0614
BD	-0.01369	1	0.01536	-0.8911	0.4072
CD	0.01553	1	0.02271	0.6837	0.5197

Final Equation in Terms of Actual Factors:

CumMassLoss =

```
         0.52161
+     1.090E-02 * Spray Dist
+     7.843E-03 * Angle
-     2.454E-03 * Current
-     8.769E-03 * Pressure
+     2.699E-04 * Spray Dist^2
-     2.591E-05 * Angle      ^2
+     5.531E-07 * Current^2
+     4.234E-05 * Pressure^2
-     1.072E-04 * Spray Dist * Angle
-     3.209E-05 * Spray Dist * Current
+     4.861E-05 * Spray Dist * Pressure
+     1.010E-05 * Angle        * Current
-     6.083E-05 * Angle        * Pressure
+     1.553E-05 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	0.06510	0.06773	-0.00263	0.980	-1.249	5.128	-1.326	1
2	0.06330	0.06597	-0.00267	0.492	-0.251	0.004	-0.230	2
3	0.04410	0.04094	0.00316	0.986	1.777	14.623	2.358	3
4	0.06180	0.07599	-0.01419	0.751	-1.907	0.730	-2.774	4
5	0.06400	0.06663	-0.00263	0.980	-1.249	5.128	-1.326	5
6	0.07460	0.06566	0.00894	0.919	2.105	3.344	3.758	6
7	0.05870	0.04976	0.00894	0.919	2.105	3.344	3.758	7
8	0.06320	0.06004	0.00316	0.986	1.777	14.623	2.358	8
9	0.01320	0.01583	-0.00263	0.980	-1.249	5.128	-1.326	9
10	0.06810	0.06597	0.00213	0.492	0.201	0.003	0.184	10
11	0.08060	0.06274	0.01786	0.141	1.293	0.018	1.390	11
12	0.05490	0.06437	-0.00947	0.872	-1.777	1.438	-2.358	12
13	0.06500	0.05712	0.00788	0.821	1.249	0.477	1.326	13
14	0.06650	0.06274	0.00376	0.141	0.272	0.001	0.250	14
15	0.01580	0.02527	-0.00947	0.872	-1.777	1.438	-2.358	15
16	0.04820	0.05767	-0.00947	0.872	-1.777	1.438	-2.358	16
17	0.05760	0.06274	-0.00514	0.141	-0.372	0.002	-0.344	17
18	0.06940	0.07887	-0.00947	0.872	-1.777	1.438	-2.358	18
19	0.07390	0.06602	0.00788	0.821	1.249	0.477	1.326	19
20	0.05890	0.06274	-0.00384	0.141	-0.278	0.001	-0.255	20
21	0.07580	0.06792	0.00788	0.821	1.249	0.477	1.326	21

Table D3. 3/16" Aluminum Statistical Analysis of Microhardness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	48691.69	1	48691.69		
Linear	37.84	4	9.46	2.486	0.0851
Quadratic	41.38	10	4.14	1.272	0.3998
Cubic	1.08	2	0.54	0.1176	0.8920
RESIDUAL	18.43	4	4.61		
TOTAL	48790.42	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	42.46	12	3.54	0.7679	0.6763
Quadratic	1.08	2	0.54	0.1176	0.8920
Cubic	0.00	0			
PURE ERR	18.43	4	4.61		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	1.951	0.3832	0.2291	121.728
Quadratic	15	6	1.804	0.8023	0.3411	292.010
Cubic	17	4	2.147	0.8133	0.0665	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	79.22	14	5.658	1.740	0.2557
RESIDUAL	19.52	6	3.253		
Lack Of Fit	1.08	2	0.542	0.1176	0.8920
Pure Error	18.43	4	4.608		
COR TOTAL	98.73	20			

ROOT MSE	1.804	R-SQUARED	0.8023
DEP MEAN	48.152	ADJ R-SQUARED	0.3411
C.V.	3.75%		

Predicted Residual Sum of Squares (PRESS) = 292.01

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	49.400	1	0.677	72.95	
A	0.464	1	1.068	0.4347	0.6790
B	-0.478	1	3.347	-0.1429	0.8910
C	-0.850	1	1.275	-0.6665	0.5299
D	0.550	1	1.275	0.4313	0.6813
A2	-0.814	1	1.071	-0.7602	0.4759
B2	-0.402	1	1.828	-0.2197	0.8334

AD	-3.555	1	2.774	-1.281	0.2473
BC	-1.304	1	1.198	-1.088	0.3182
BD	1.563	1	1.859	0.8408	0.4327
CD	-7.115	1	2.748	-2.589	0.0413

Final Equation in Terms of Actual Factors:

```
     Microhard =
                          -229.673
             +              2.6664 * Spray Dist
             -             0.90457 * Angle
             +             0.74353 * Current
             +              3.5332 * Pressure
             -           9.046E-02 * Spray Dist^2
             -           7.933E-04 * Angle      ^2
             -           1.900E-04 * Current^2
             -           2.733E-03 * Pressure^2
             +           5.938E-02 * Spray Dist * Angle
             +           1.607E-02 * Spray Dist * Current
             -             0.11850 * Spray Dist * Pressure
             -           5.795E-04 * Angle      * Current
             +           6.945E-03 * Angle      * Pressure
             -           7.115E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	44.800	44.741	0.059	0.980	0.231	0.175	0.212	1
2	45.200	48.121	-2.921	0.492	-2.272	0.333	-5.558	2
3	44.000	44.117	-0.117	0.986	-0.543	1.366	-0.509	3
4	48.600	48.190	0.410	0.751	0.455	0.042	0.423	4
5	53.000	52.941	0.059	0.980	0.231	0.175	0.212	5
6	44.800	45.092	-0.292	0.919	-0.569	0.244	-0.534	6
7	48.200	48.492	-0.292	0.919	-0.569	0.244	-0.534	7
8	46.900	47.017	-0.117	0.986	-0.543	1.366	-0.509	8
9	46.300	46.241	0.059	0.980	0.231	0.175	0.212	9
10	51.100	48.121	2.979	0.492	2.318	0.347	6.535	10
11	49.100	49.400	-0.300	0.141	-0.179	0.000	-0.164	11
12	49.400	49.050	0.350	0.872	0.543	0.134	0.509	12
13	49.300	49.476	-0.176	0.821	-0.231	0.016	-0.212	13
14	48.500	49.400	-0.900	0.141	-0.538	0.003	-0.504	14
15	49.100	48.750	0.350	0.872	0.543	0.134	0.509	15
16	48.700	48.350	0.350	0.872	0.543	0.134	0.509	16
17	49.400	49.400	0.000	0.141	0.000	0.000	0.000	17
18	47.000	46.650	0.350	0.872	0.543	0.134	0.509	18
19	48.400	48.576	-0.176	0.821	-0.231	0.016	-0.212	19
20	49.900	49.400	0.500	0.141	0.299	0.001	0.275	20
21	49.500	49.676	-0.176	0.821	-0.231	0.016	-0.212	21

Table D4. 3/16" Aluminum Statistical Analysis of Oxides

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	302.5	1	302.5		
Linear	21.3	4	5.3	0.9016	0.4861
Quadratic	82.6	10	8.3	4.139	0.0479
Cubic	4.6	2	2.3	1.234	0.3825
RESIDUAL	7.4	4	1.9		
TOTAL	418.4	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	87.2	12	7.3	3.924	0.0988
Quadratic	4.6	2	2.3	1.234	0.3825
Cubic	0.0	0			
PURE ERR	7.4	4	1.9		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	2.43	0.1839	-0.0201	185.93
Quadratic	15	6	1.41	0.8967	0.6556	968.06
Cubic	17	4	1.36	0.9361	0.6805	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	104.0	14	7.43	3.720	0.0575
RESIDUAL	12.0	6	2.00		
Lack Of Fit	4.6	2	2.28	1.234	0.3825
Pure Error	7.4	4	1.85		
COR TOTAL	115.9	20			

ROOT MSE	1.41	R-SQUARED	0.8967
DEP MEAN	3.80	ADJ R-SQUARED	0.6556
C.V.	37.23%		

Predicted Residual Sum of Squares (PRESS) = 968.1

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	3.18	1	0.53	5.996	
A	2.04	1	0.84	2.436	0.0508
B	-6.44	1	2.62	-2.457	0.0493
C	0.85	1	1.00	0.8508	0.4275
D	1.45	1	1.00	1.451	0.1969
A2	0.94	1	0.84	1.124	0.3041

AC	5.57	1	2.01	2.770	0.0324
AD	-6.62	1	2.17	-3.044	0.0227
BC	0.93	1	0.94	0.9935	0.3588
BD	2.78	1	1.46	1.913	0.1043
CD	-6.69	1	2.15	-3.107	0.0209

Final Equation in Terms of Actual Factors:

```
        Oxides =
                        -75.39
            +          3.8989 * Spray Dist
            -          1.4429 * Angle
            +         0.57592 * Current
            +         0.52514 * Pressure
            +         0.10475 * Spray Dist^2
            -       7.063E-03 * Angle      ^2
            -       1.469E-04 * Current^2
            +       1.416E-02 * Pressure^2
            +         0.11613 * Spray Dist * Angle
            +       1.857E-02 * Spray Dist * Current
            -         0.22055 * Spray Dist * Pressure
            +       4.144E-04 * Angle        * Current
            +       1.238E-02 * Angle        * Pressure
            -       6.690E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	6.60	6.42	0.18	0.980	0.914	2.746	0.900	1
2	2.70	2.08	0.62	0.492	0.611	0.024	0.576	2
3	5.30	5.51	-0.21	0.986	-1.264	7.394	-1.347	3
4	7.10	6.13	0.97	0.751	1.378	0.381	1.522	4
5	9.40	9.22	0.18	0.980	0.914	2.746	0.900	5
6	0.70	1.31	-0.61	0.919	-1.510	1.720	-1.750	6
7	4.60	5.21	-0.61	0.919	-1.510	1.720	-1.750	7
8	1.00	1.21	-0.21	0.986	-1.264	7.394	-1.347	8
9	1.40	1.22	0.18	0.980	0.914	2.746	0.900	9
10	1.50	2.08	-0.58	0.492	-0.581	0.022	-0.546	10
11	5.20	3.18	2.02	0.141	1.542	0.026	1.812	11
12	6.80	6.16	0.64	0.872	1.264	0.727	1.347	12
13	5.50	6.05	-0.55	0.821	-0.914	0.256	-0.900	13
14	2.30	3.18	-0.88	0.141	-0.672	0.005	-0.638	14
15	2.40	1.76	0.64	0.872	1.264	0.727	1.347	15
16	1.50	0.86	0.64	0.872	1.264	0.727	1.347	16
17	2.00	3.18	-1.18	0.141	-0.901	0.009	-0.885	17
18	3.20	2.56	0.64	0.872	1.264	0.727	1.347	18
19	2.60	3.15	-0.55	0.821	-0.914	0.256	-0.900	19
20	2.40	3.18	-0.78	0.141	-0.596	0.004	-0.561	20
21	5.50	6.05	-0.55	0.821	-0.914	0.256	-0.900	21

Table D5. 3/16" Aluminum Statistical Analysis of Porosity

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	2028.6	1	2028.6		
Linear	203.3	4	50.8	3.888	0.0216
Quadratic	68.7	10	6.9	0.2935	0.9575
Cubic	27.1	2	13.5	0.4779	0.6515
RESIDUAL	113.4	4	28.3		
TOTAL	2441.1	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	95.8	12	8.0	0.2816	0.9608
Quadratic	27.1	2	13.5	0.4779	0.6515
Cubic	0.0	0			
PURE ERR	113.4	4	28.3		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	3.62	0.4929	0.3661	370.54
Quadratic	15	6	4.84	0.6594	-0.1352	4597.98
Cubic	17	4	5.32	0.7251	-0.3744	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	272.0	14	19.43	0.8299	0.6404
RESIDUAL	140.5	6	23.41		
Lack Of Fit	27.1	2	13.54	0.4779	0.6515
Pure Error	113.4	4	28.34		
COR TOTAL	412.4	20			

ROOT MSE	4.84	R-SQUARED	0.6594
DEP MEAN	9.83	ADJ R-SQUARED	-0.1352
C.V.	49.23%		

Predicted Residual Sum of Squares (PRESS) = 4598.0

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	9.63	1	1.82	5.302	
A	2.51	1	2.87	0.8775	0.4140
B	-2.21	1	8.98	-0.2464	0.8136
C	-3.20	1	3.42	-0.9353	0.3857
D	-2.95	1	3.42	-0.8623	0.4217

AB	-0.57	1	6.56	-8.70E-02	0.9335
AC	-1.42	1	6.89	-0.2058	0.8438
AD	-2.27	1	7.44	-0.3053	0.7705
BC	-0.02	1	3.21	-7.13E-03	0.9945
BD	-0.85	1	4.99	-0.1702	0.8704
CD	-2.00	1	7.37	-0.2715	0.7951

Final Equation in Terms of Actual Factors:

```
Porosity =
                 -239.19
      +           13.883 * Spray Dist
      +          0.37079 * Angle
      +          0.24054 * Current
      +           2.9714 * Pressure
      -          0.16989 * Spray Dist^2
      -        6.838E-05 * Angle      ^2
      -        4.140E-05 * Current^2
      -        7.724E-03 * Pressure^2
      -        8.449E-03 * Spray Dist * Angle
      -        4.722E-03 * Spray Dist * Current
      -        7.574E-02 * Spray Dist * Pressure
      -        1.019E-05 * Angle        * Current
      -        3.772E-03 * Angle        * Pressure
      -        2.001E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	5.10	5.60	-0.50	0.980	-0.728	1.741	-0.696	1
2	1.90	5.59	-3.69	0.492	-1.069	0.074	-1.085	2
3	4.40	4.83	-0.43	0.986	-0.741	2.544	-0.710	3
4	8.30	8.94	-0.64	0.751	-0.263	0.014	-0.242	4
5	9.70	10.20	-0.50	0.980	-0.728	1.741	-0.696	5
6	16.30	16.66	-0.36	0.919	-0.260	0.051	-0.238	6
7	8.00	8.36	-0.36	0.919	-0.260	0.051	-0.238	7
8	10.40	10.83	-0.43	0.986	-0.741	2.544	-0.710	8
9	18.30	18.80	-0.50	0.980	-0.728	1.741	-0.696	9
10	10.20	5.59	4.61	0.492	1.337	0.116	1.457	10
11	11.40	9.63	1.77	0.141	0.394	0.002	0.365	11
12	11.90	10.62	1.28	0.872	0.741	0.250	0.710	12
13	13.30	11.81	1.49	0.821	0.728	0.162	0.696	13
14	6.50	9.63	-3.13	0.141	-0.698	0.005	-0.665	14
15	15.20	13.92	1.28	0.872	0.741	0.250	0.710	15
16	13.70	12.42	1.28	0.872	0.741	0.250	0.710	16
17	12.50	9.63	2.87	0.141	0.640	0.004	0.605	17
18	7.30	6.02	1.28	0.872	0.741	0.250	0.710	18
19	13.30	11.81	1.49	0.821	0.728	0.162	0.696	19
20	1.30	9.63	-8.33	0.141	-1.858	0.038	-2.603	20
21	7.40	5.91	1.49	0.821	0.728	0.162	0.696	21

Table D6. 3/16" Aluminum Statistical Analysis of Roughness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	6556.1	1	6556.1		
Linear	172.1	4	43.0	7.673	0.0012
Quadratic	76.0	10	7.6	3.322	0.0775
Cubic	1.2	2	0.6	0.1986	0.8275
RESIDUAL	12.5	4	3.1		
TOTAL	6817.8	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	77.2	12	6.4	2.062	0.2532
Quadratic	1.2	2	0.6	0.1986	0.8275
Cubic	0.0	0			
PURE ERR	12.5	4	3.1		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	2.37	0.6573	0.5716	218.35
Quadratic	15	6	1.51	0.9476	0.8253	267.54
Cubic	17	4	1.77	0.9523	0.7616	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	248.0	14	17.72	7.747	0.0095
RESIDUAL	13.7	6	2.29		
Lack Of Fit	1.2	2	0.62	0.1986	0.8275
Pure Error	12.5	4	3.12		
COR TOTAL	261.7	20			

ROOT MSE	1.51	R-SQUARED	0.9476
DEP MEAN	17.67	ADJ R-SQUARED	0.8253
C.V.	8.56%		

Predicted Residual Sum of Squares (PRESS) = 267.5

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	14.70	1	0.57	25.89	
A	0.04	1	0.90	4.03E-02	0.9692
B	-1.21	1	2.81	-0.4313	0.6813
C	-2.54	1	1.07	-2.380	0.0548
D	-0.41	1	1.07	-0.3834	0.7146

AB	2.11	1	2.05	1.030	0.3429
AC	2.34	1	2.15	1.086	0.3191
AD	-2.34	1	2.33	-1.008	0.3523
BC	-2.79	1	1.00	-2.773	0.0323
BD	0.31	1	1.56	0.1961	0.8510
CD	-4.98	1	2.30	-2.162	0.0739

Final Equation in Terms of Actual Factors:

Ra Rough. =

```
              -69.25
  -         1.0523 * Spray Dist
  -        0.55554 * Angle
  +        0.52584 * Current
  +        0.61061 * Pressure
  +        0.18556 * Spray Dist^2
  +      2.877E-03 * Angle       ^2
  -      1.688E-05 * Current^2
  +      8.367E-03 * Pressure^2
  +      3.126E-02 * Spray Dist * Angle
  +      7.792E-03 * Spray Dist * Current
  -      7.817E-02 * Spray Dist * Pressure
  -      1.238E-03 * Angle       * Current
  +      1.358E-03 * Angle       * Pressure
  -      4.982E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	17.41	17.26	0.15	0.980	0.682	1.529	0.648	1
2	15.22	16.33	-1.11	0.492	-1.033	0.069	-1.040	2
3	26.44	26.50	-0.06	0.986	-0.322	0.480	-0.296	3
4	18.04	17.49	0.55	0.751	0.732	0.107	0.700	4
5	18.36	18.21	0.15	0.980	0.682	1.529	0.648	5
6	19.49	19.75	-0.26	0.919	-0.607	0.278	-0.572	6
7	19.11	19.37	-0.26	0.919	-0.607	0.278	-0.572	7
8	19.45	19.51	-0.06	0.986	-0.322	0.480	-0.296	8
9	24.78	24.63	0.15	0.980	0.682	1.529	0.648	9
10	17.36	16.33	1.03	0.492	0.952	0.059	0.943	10
11	12.36	14.70	-2.34	0.141	-1.669	0.030	-2.082	11
12	16.58	16.41	0.17	0.872	0.322	0.047	0.296	12
13	16.93	17.37	-0.44	0.821	-0.682	0.142	-0.648	13
14	14.35	14.70	-0.35	0.141	-0.250	0.001	-0.229	14
15	23.12	22.95	0.17	0.872	0.322	0.047	0.296	15
16	17.25	17.08	0.17	0.872	0.322	0.047	0.296	16
17	16.18	14.70	1.48	0.141	1.056	0.012	1.068	17
18	12.16	11.99	0.17	0.872	0.322	0.047	0.296	18
19	15.51	15.95	-0.44	0.821	-0.682	0.142	-0.648	19
20	16.26	14.70	1.56	0.141	1.113	0.014	1.141	20
21	14.69	15.13	-0.44	0.821	-0.682	0.142	-0.648	21

Table D7. Minitab Analysis for 3/16" Aluminum

```
MTB > REGRESS C6 20 C1-C5 C7-C21;
SUBC> RESIDUALS C22.
```

The regression equation is

CML = - 0.158 + 0.0071 P + 0.0145 O +0.000000 BS2 -0.000069 R2 -0.000320 P2 - 0.00136 O2 +0.000012 MH2 + 74.6 1/BS + 0.027 1/R + 0.162 1/P - 0.009 1/O - 0.139 1/P2 + 0.0383 1/O2

Predictor	Coef	Stdev	t-ratio	p
Constant	-0.1583	0.2308	-0.69	0.515
P	0.00707	0.01043	0.68	0.519
O	0.01452	0.01672	0.87	0.414
BS2	0.00000005	0.00000004	1.16	0.282
R2	-0.00006895	0.00005369	-1.28	0.240
P2	-0.0003203	0.0004076	-0.79	0.458
O2	-0.001359	0.001234	-1.10	0.307
MH2	0.00001152	0.00002557	0.45	0.666
1/BS	74.56	93.60	0.80	0.452
1/R	0.0270	0.6572	0.04	0.968
1/P	0.1625	0.2286	0.71	0.500
1/O	-0.0088	0.1102	-0.08	0.939
1/P2	-0.1385	0.2008	-0.69	0.513
1/O2	0.03829	0.04850	0.79	0.456

s = 0.008907   R-sq = 90.6%   R-sq(adj) = 73.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	13	0.00536897	0.00041300	5.21	0.018
Error	7	0.00055534	0.00007933		
Total	20	0.00592432			

SOURCE	DF	SEQ SS
P	1	0.00070305
O	1	0.00007135
BS2	1	0.00081434
R2	1	0.00230348
P2	1	0.00012037
O2	1	0.00001352
MH2	1	0.00036561
1/BS	1	0.00001308
1/R	1	0.00002206
1/P	1	0.00007662
1/O	1	0.00076386
1/P2	1	0.00005219
1/O2	1	0.00004945

Unusual Observations

Obs.	P	CML	Fit	Stdev.Fit	Residual	St.Resid
20	1.3	0.05890	0.05887	0.00890	0.00003	0.08 X

X denotes an obs. whose X value gives it large influence.

RESIDUALS

-0.0059443	-0.0001744	0.0045388	0.0035083	0.0019615	-0.0004366
0.0003057	0.0011575	0.0029683	-0.0021148	0.0016193	-0.0101025
0.0059839	0.0020455	-0.0119288	-0.0016474	0.0011412	-0.0064254
0.0114855	0.0000280	0.0020307			

Appendix E. Results for the 1/8" Zinc Wire System

Figures E1-E21: Photomicrographs E1-E21
Figures E22-E27: Perturbation Plots
Tables E1-E6: Design Expert Analysis
Table E7: Minitab Analysis

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PHOTO 1 TAKEN AT 200X

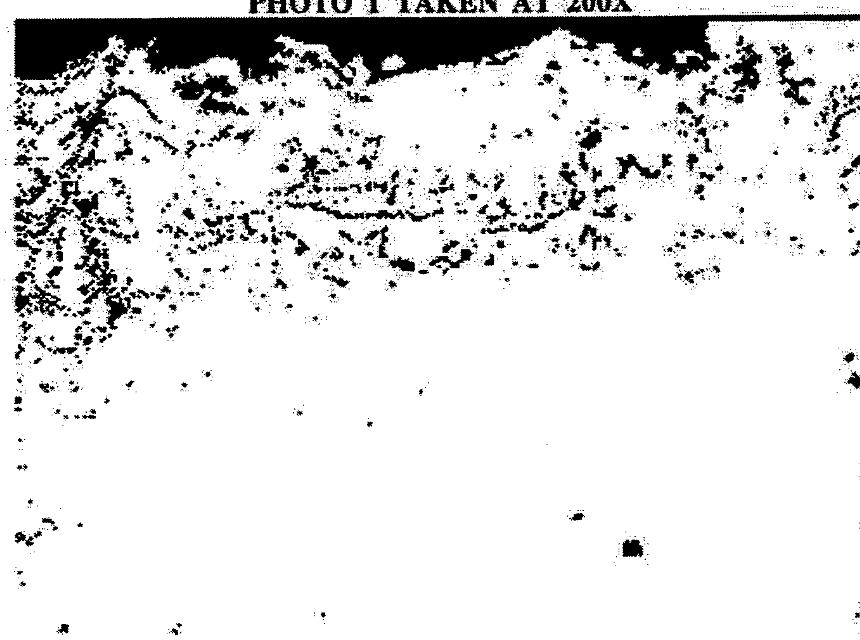

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-1Z

Figure E1. Photomicrograph of Coating Z1 (1/8" zinc)

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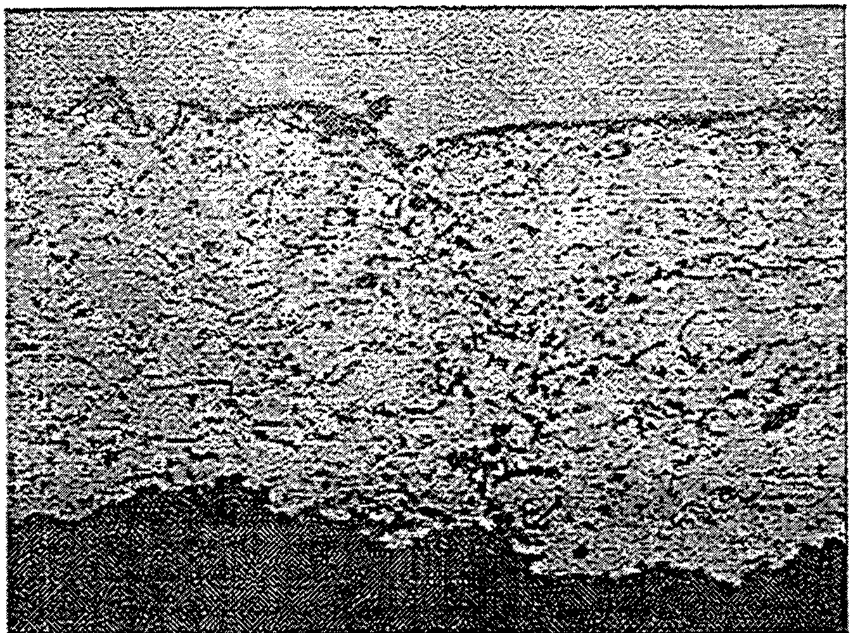

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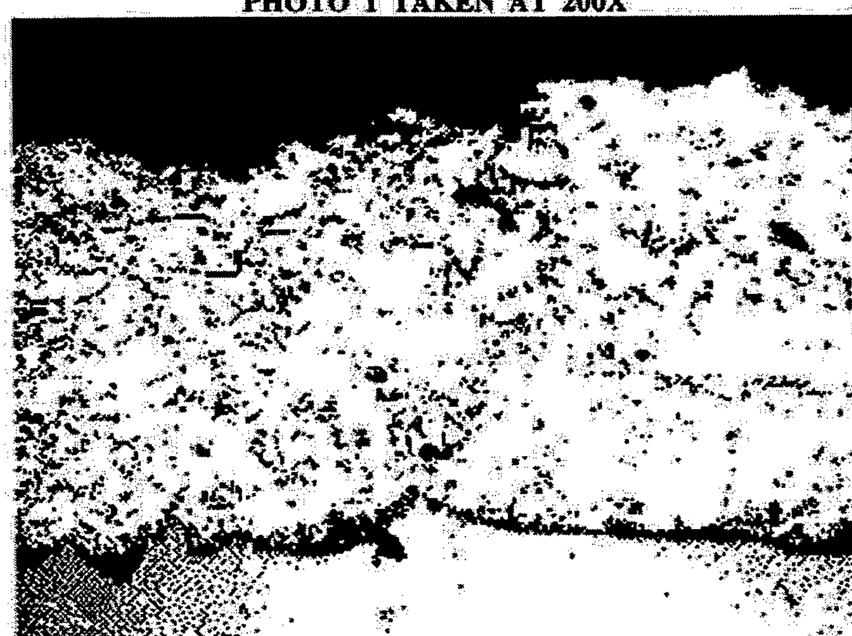

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-2Z

Figure E2. Photomicrograph of Coating Z2 (1/8" zinc)

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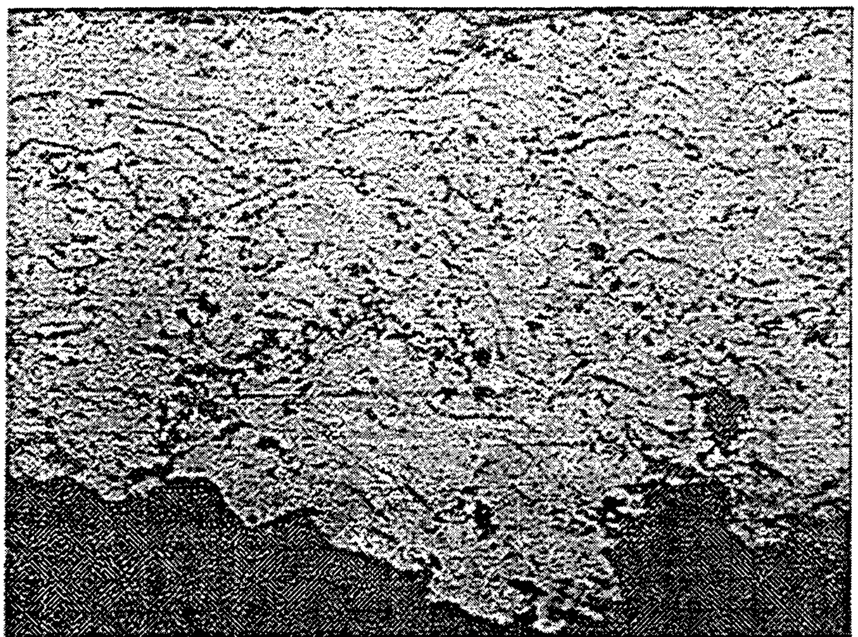

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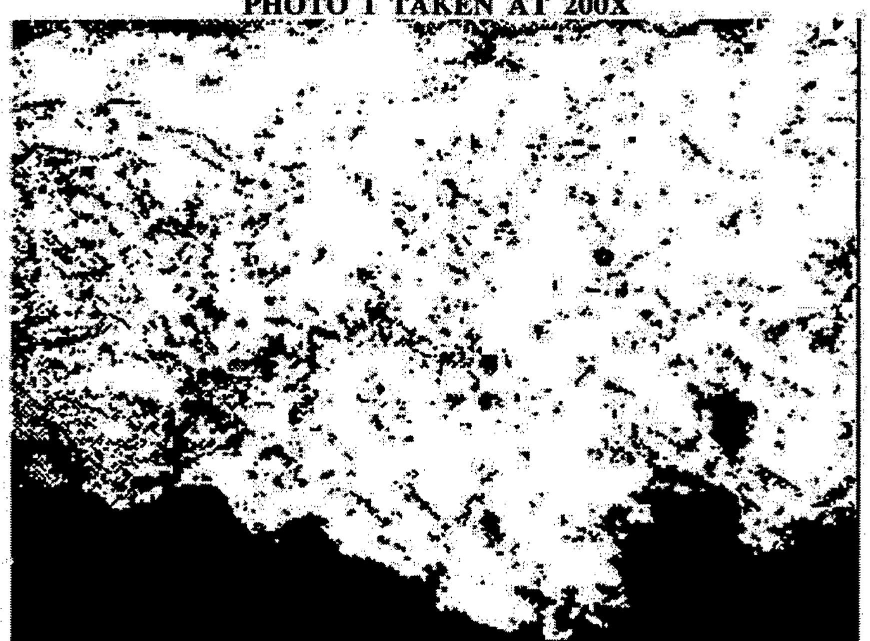

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-3Z

Figure E3. Photomicrograph of Coating Z3 (1/8" zinc)

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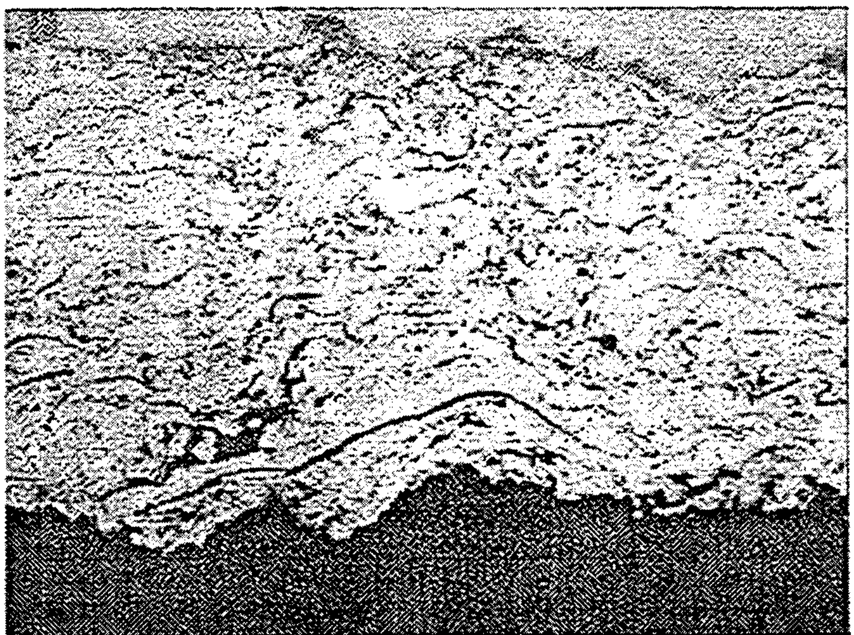

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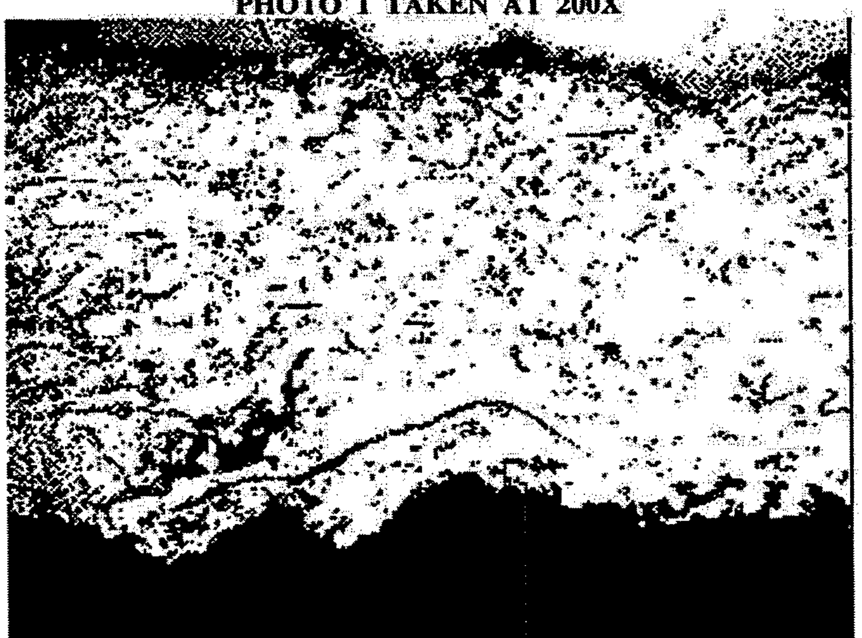

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-4Z

Figure E4. Photomicrograph of Coating Z4 (1/8" zinc)

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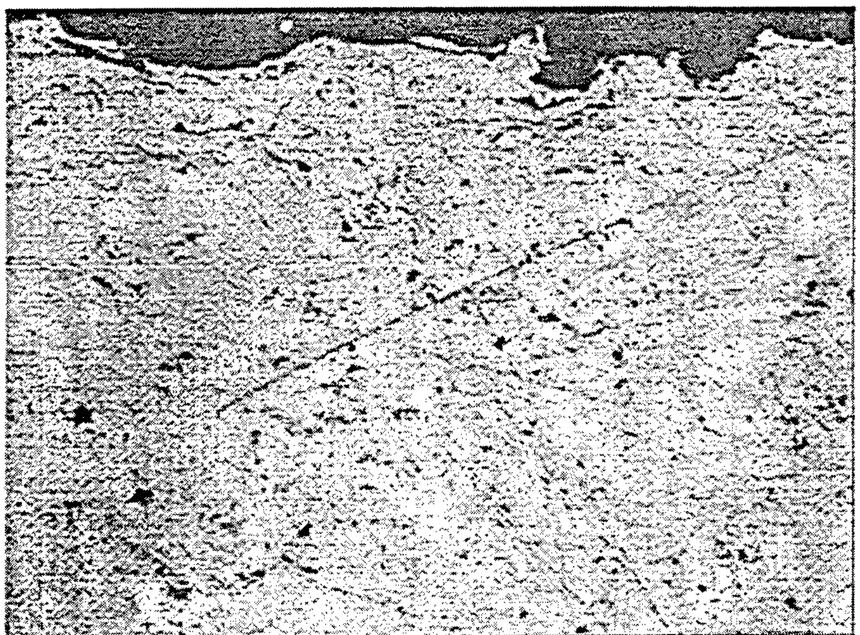

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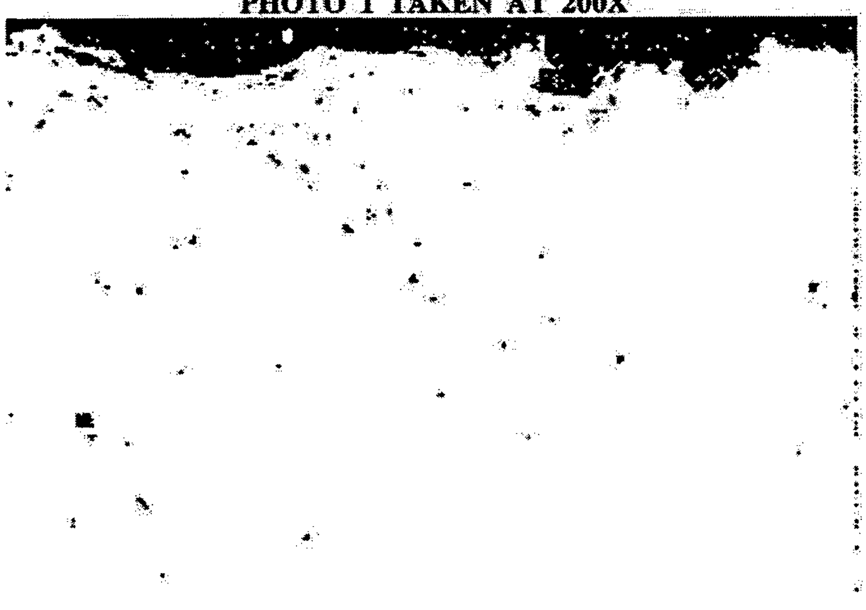

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-5Z

Figure E5. Photomicrograph of Coating Z5 (1/8" zinc)

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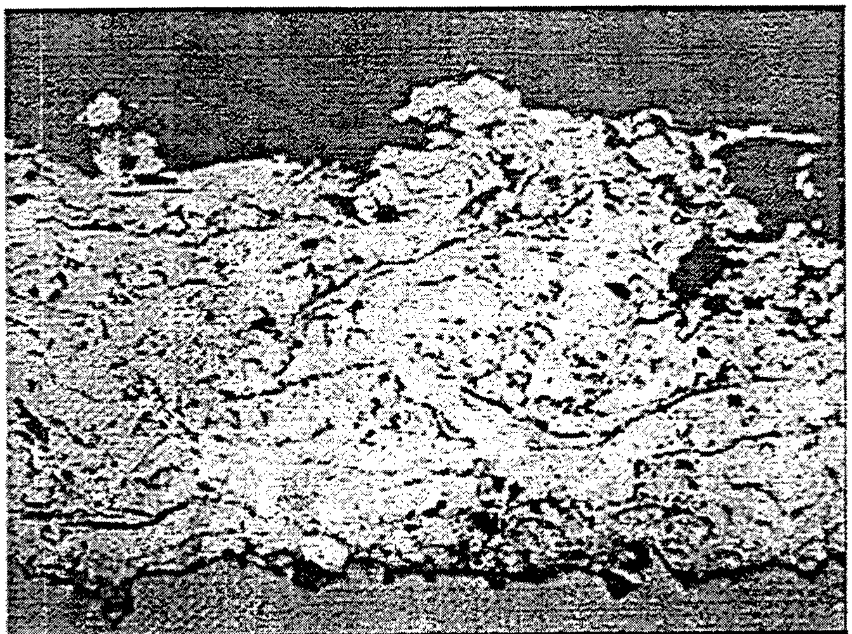

PHOTO 1 TAKEN AT 200X

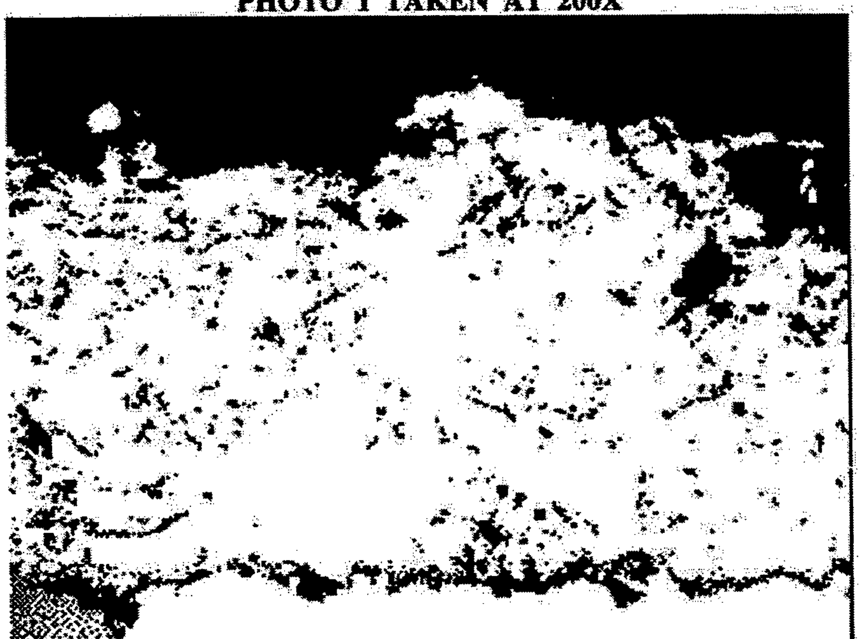

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-6Z

Figure E6. Photomicrograph of Coating Z6 (1/8" zinc)

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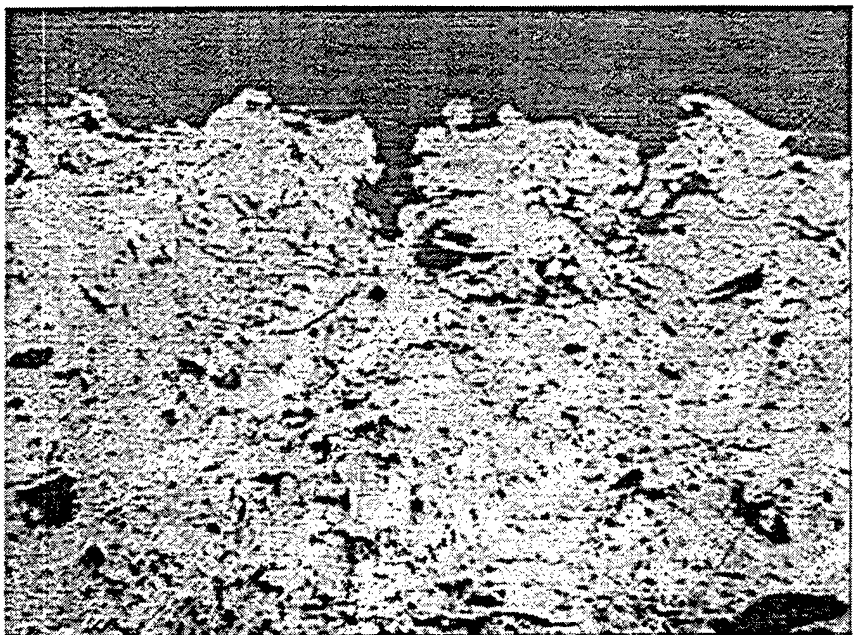

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-7Z

Figure E7. Photomicrograph of Coating Z7 (1/8" zinc)

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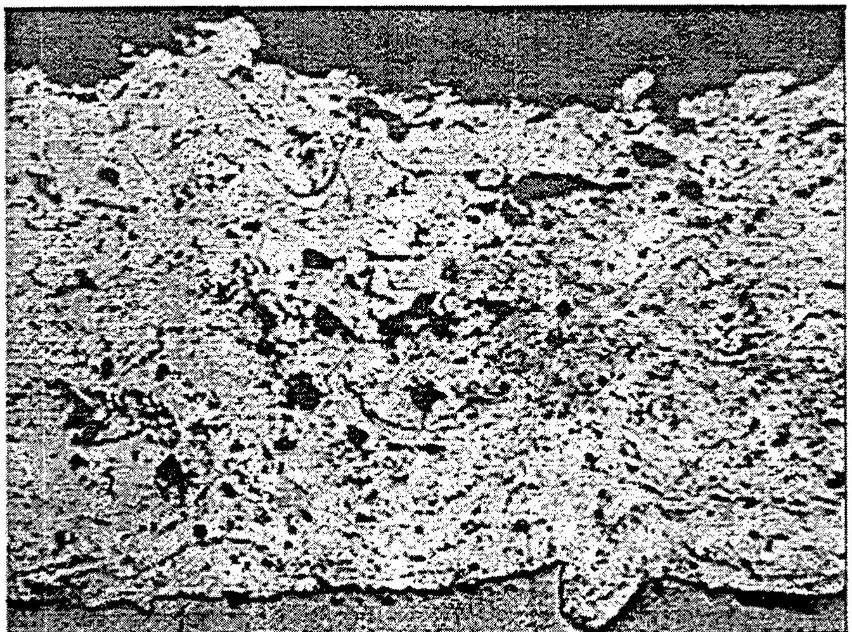

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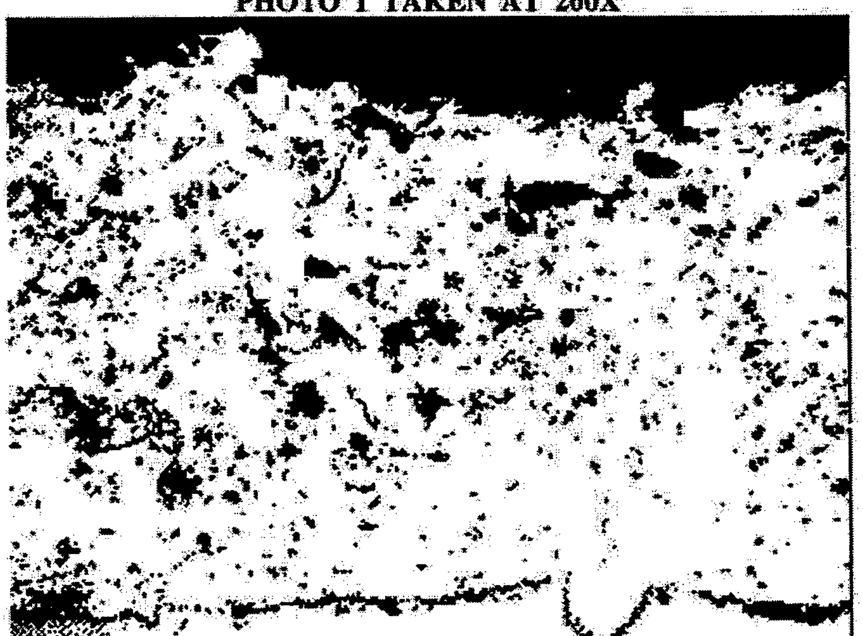

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-8Z

Figure E8. Photomicrograph of Coating Z8 (1/8" zinc)

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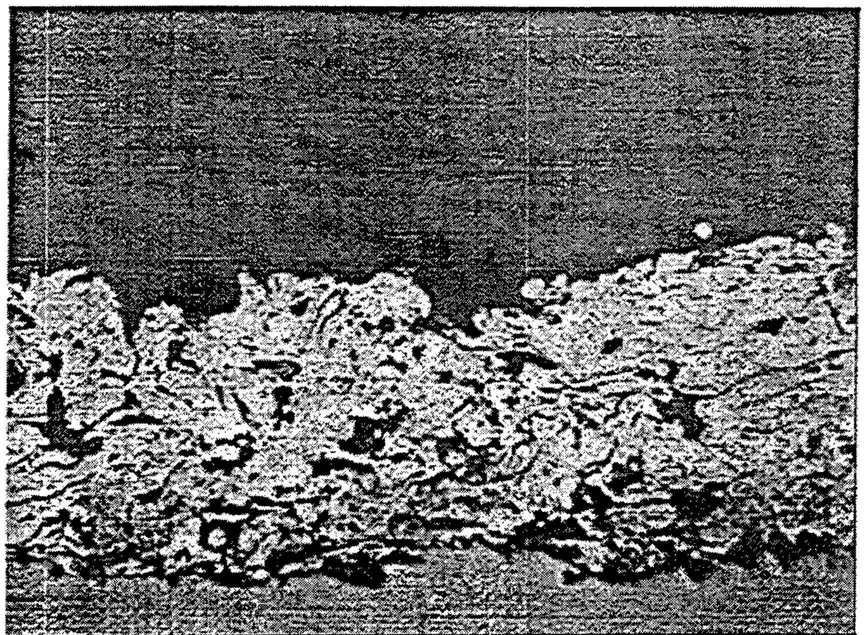

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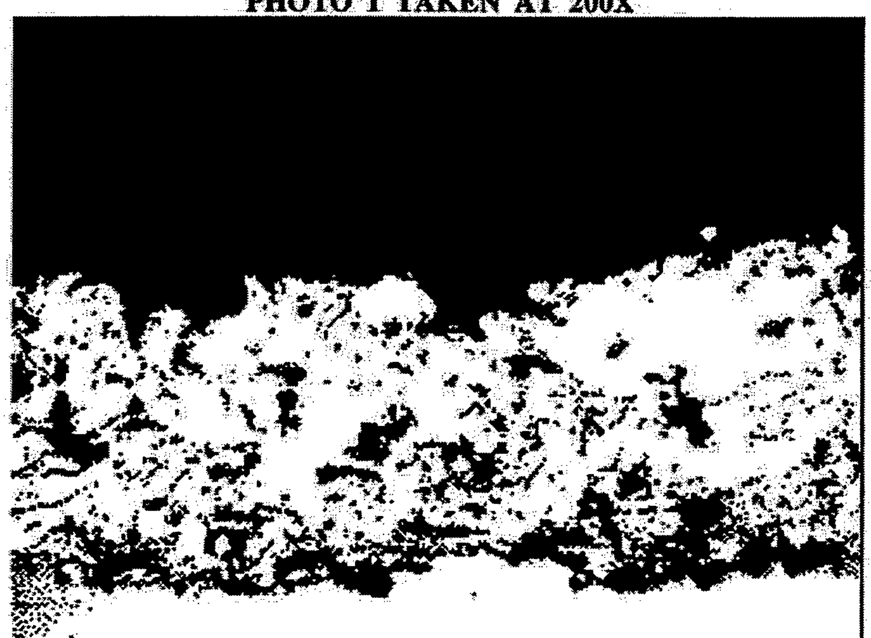

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-9Z

Figure E9. Photomicrograph of Coating Z9 (1/8" zinc)

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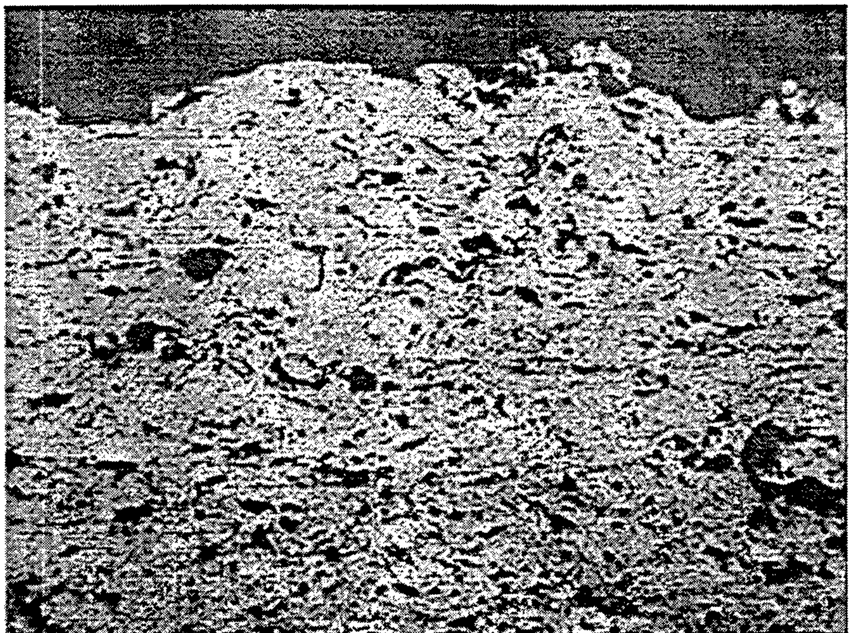

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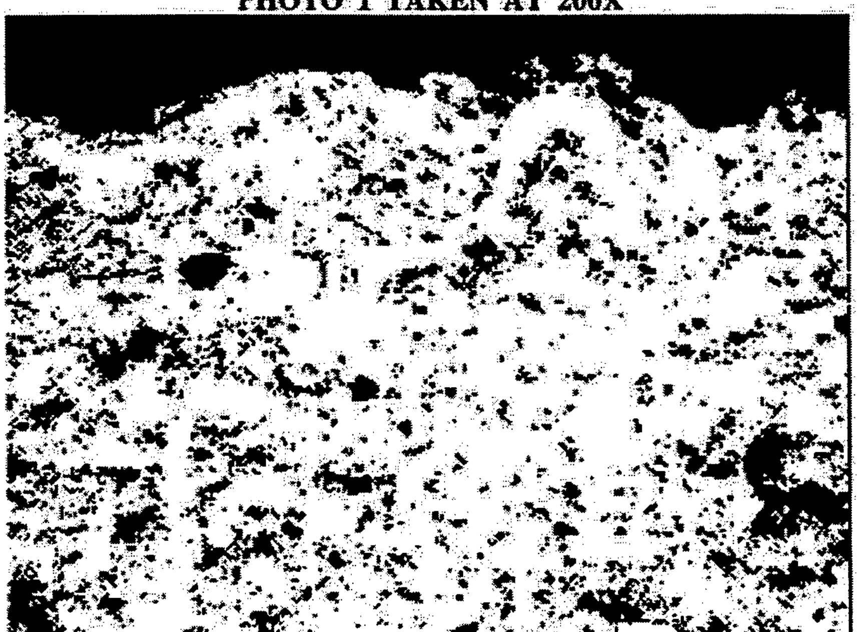

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-10Z

Figure E10. Photomicrograph of Coating Z10 (1/8" zinc)

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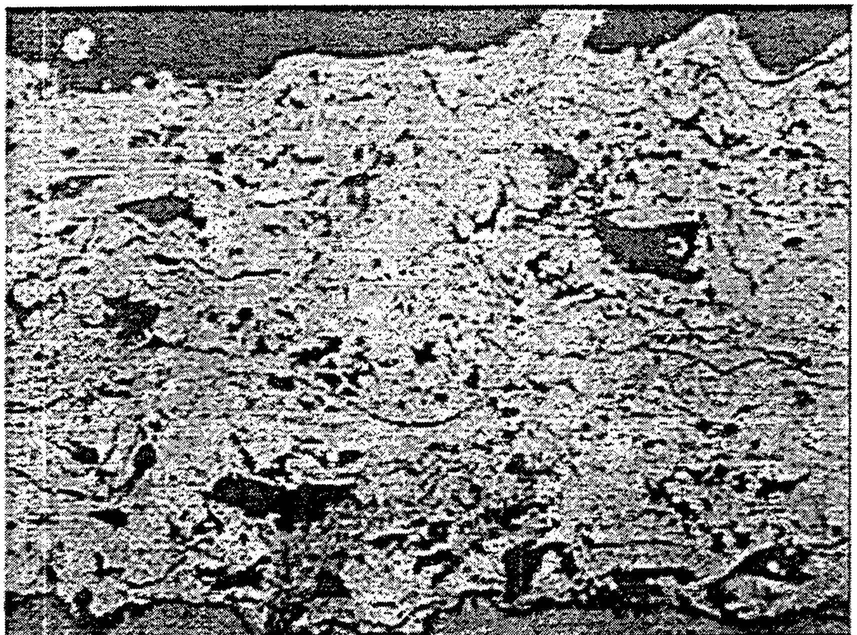

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-11Z

Figure E11. Photomicrograph of Coating Z11 (1/8" zinc)

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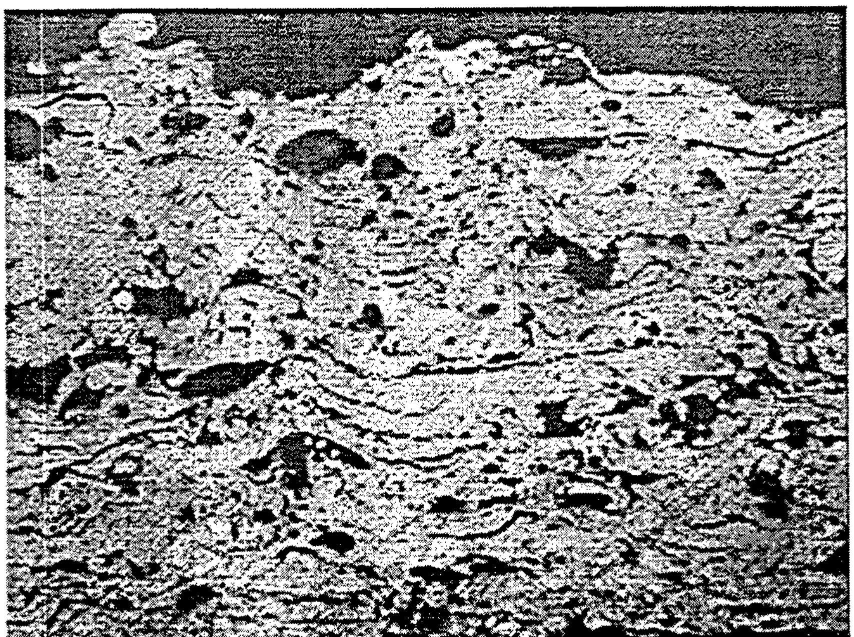

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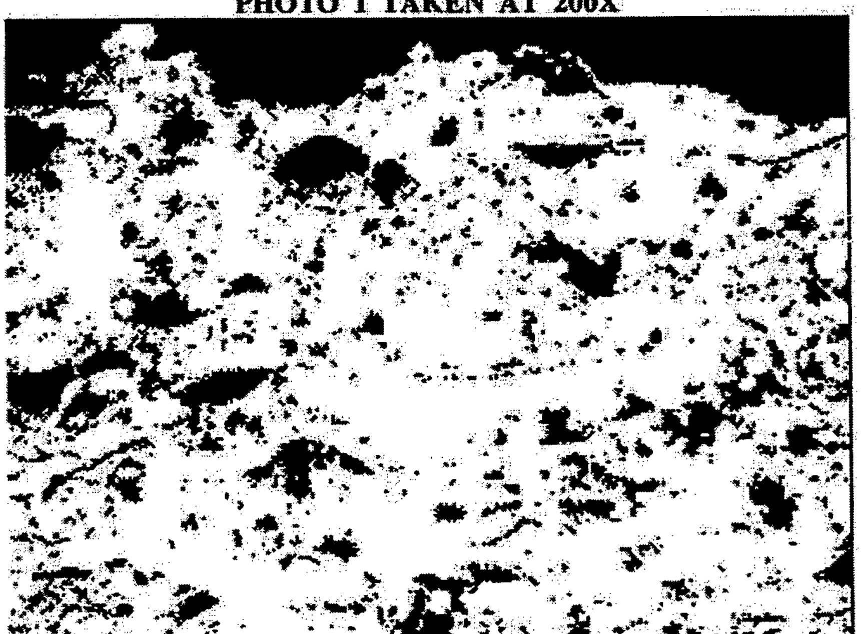

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-12Z

Figure E12. Photomicrograph of Coating Z12 (1/8" zinc)

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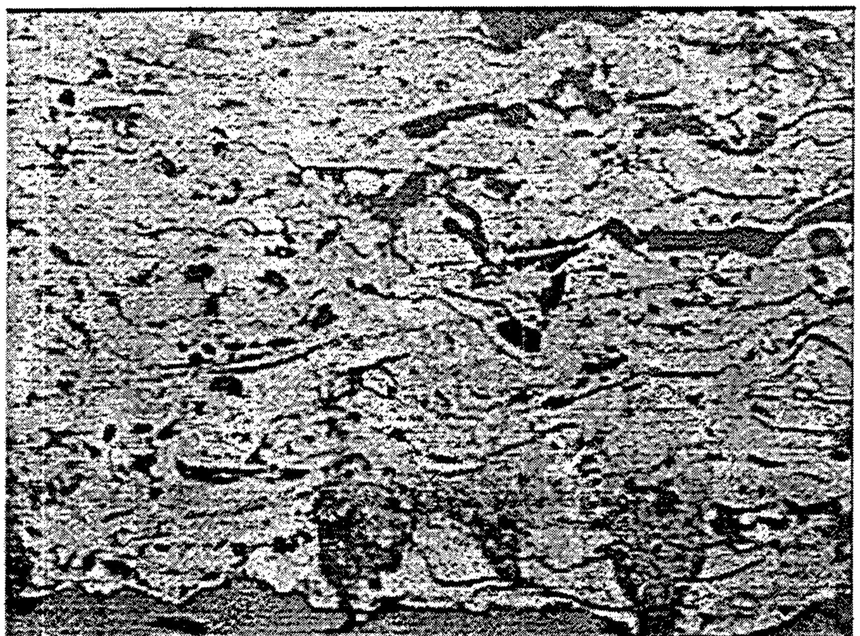

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-13Z

Figure E13. Photomicrograph of Coating Z13 (1/8" zinc)

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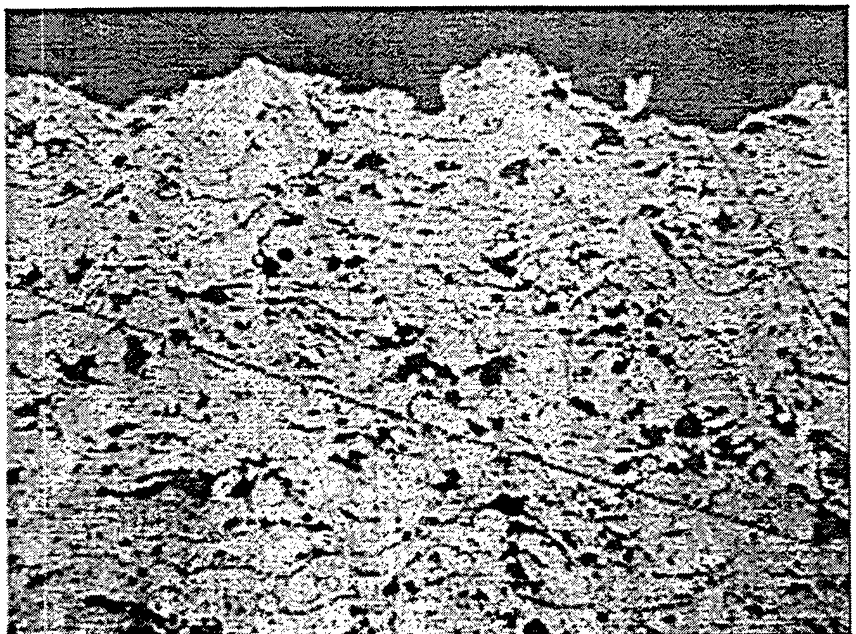

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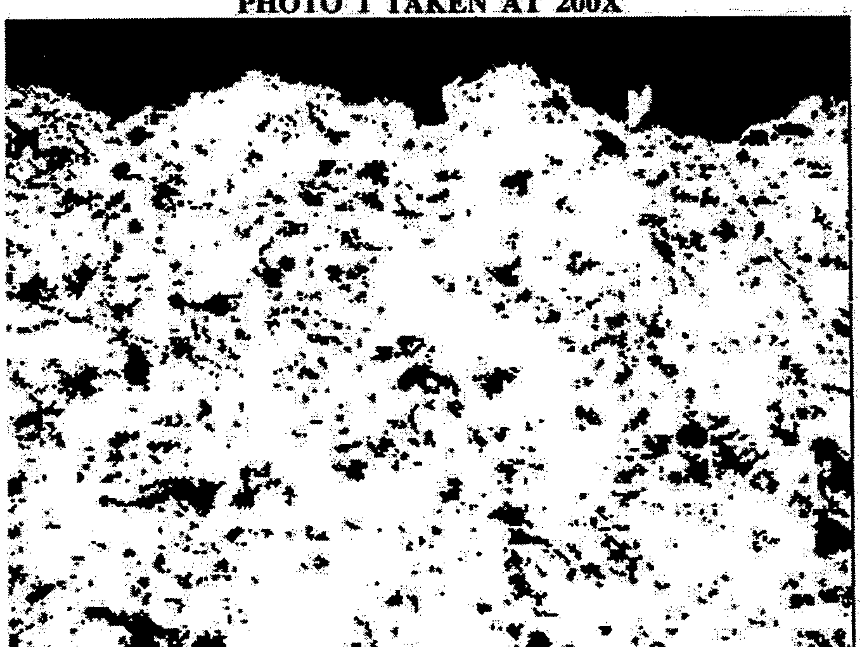

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-14Z

Figure E14. Photomicrograph of Coating Z14 (1/8" zinc)

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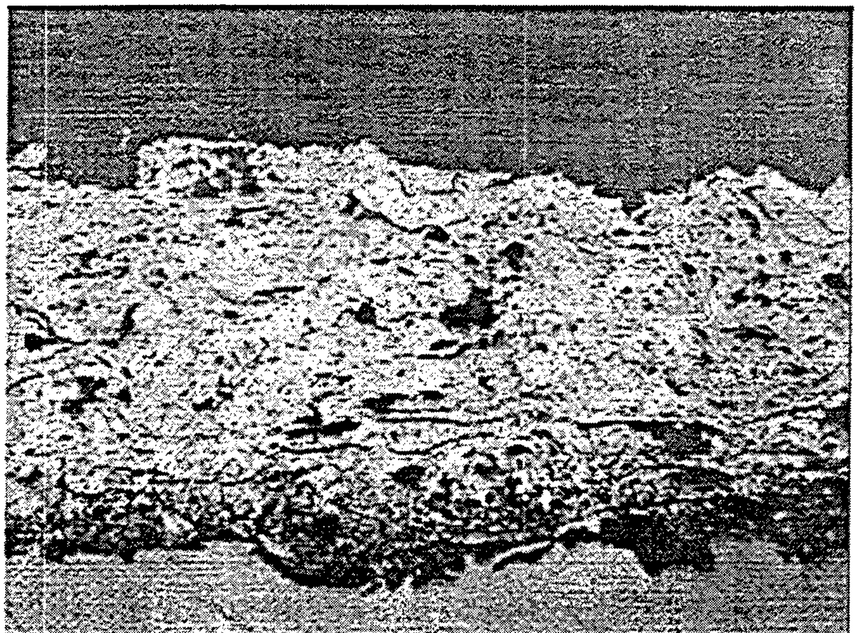

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-15Z

Figure E15. Photomicrograph of Coating Z15 (1/8" zinc)

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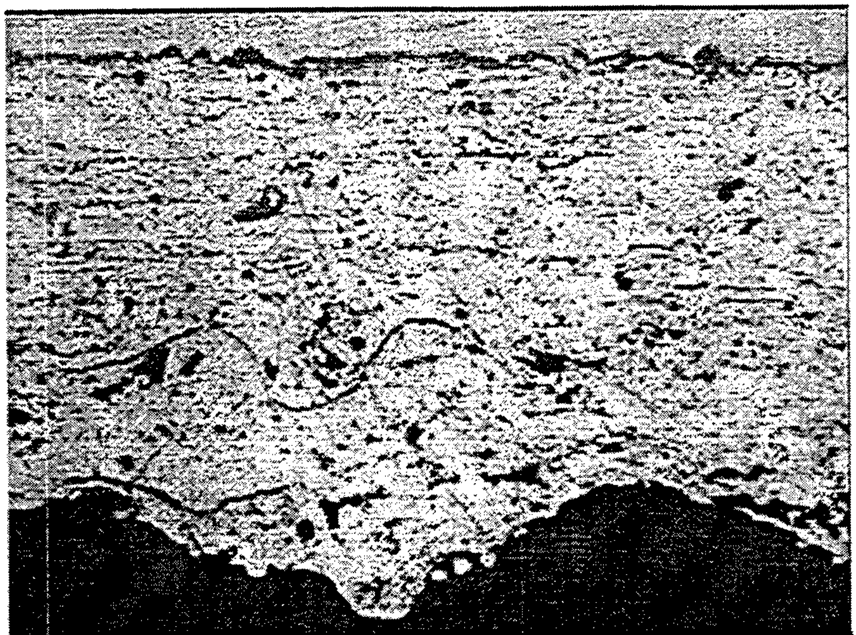

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-16Z

Figure E16. Photomicrograph of Coating Z16 (1/8" zinc)

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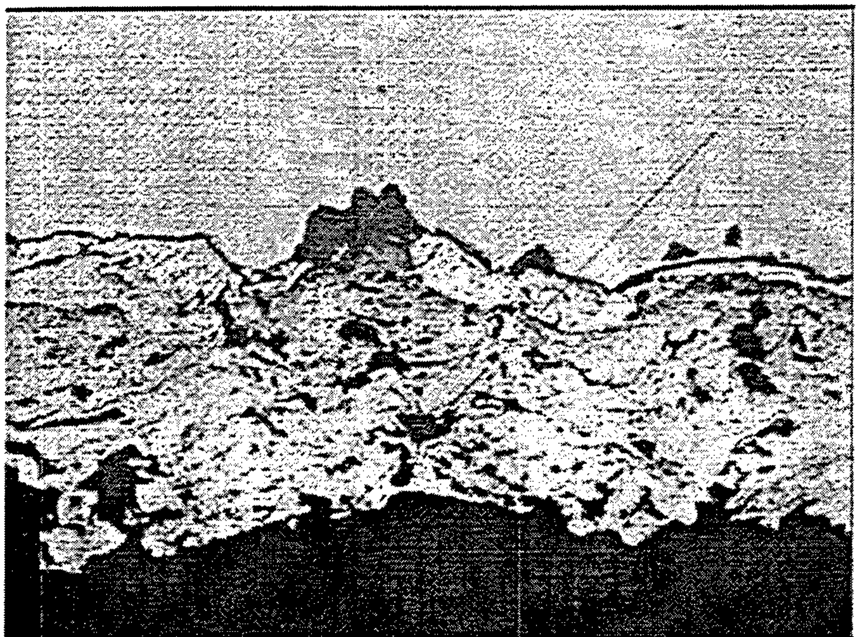

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-17Z

Figure E17. Photomicrograph of Coating Z17 (1/8" zinc)

PROTECH LAB CORP.

Materials Testing Services

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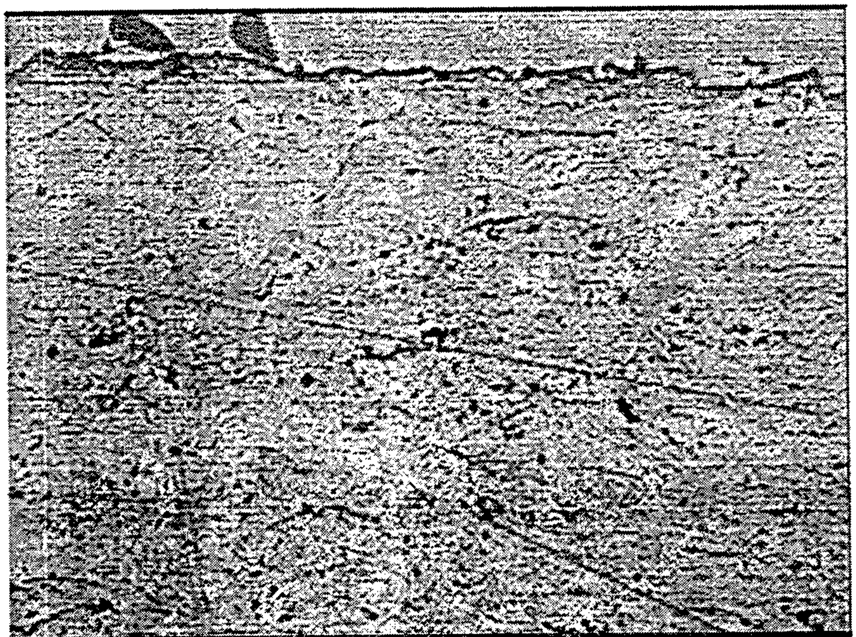

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-18Z

Figure E18. Photomicrograph of Coating Z18 (1/8" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

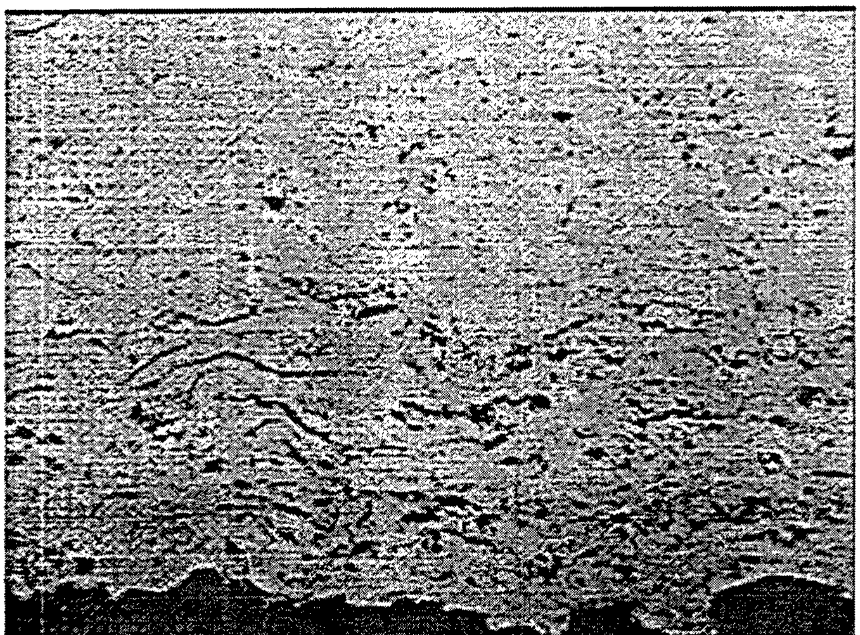

PHOTO 1 TAKEN AT 200X

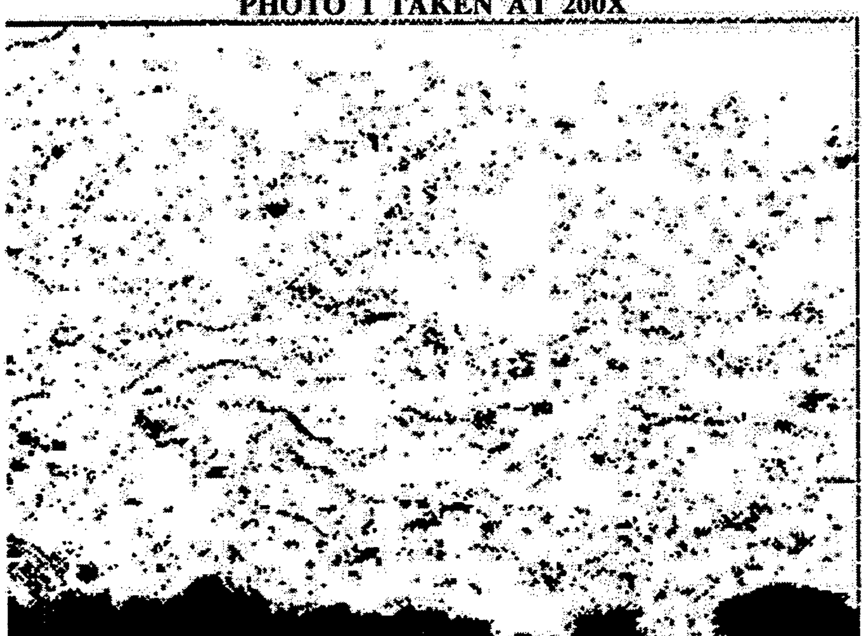

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-19Z

Figure E19. Photomicrograph of Coating Z19 (1/8" zinc)

PROTECH LAB CORP.
Materials Testing Services
9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

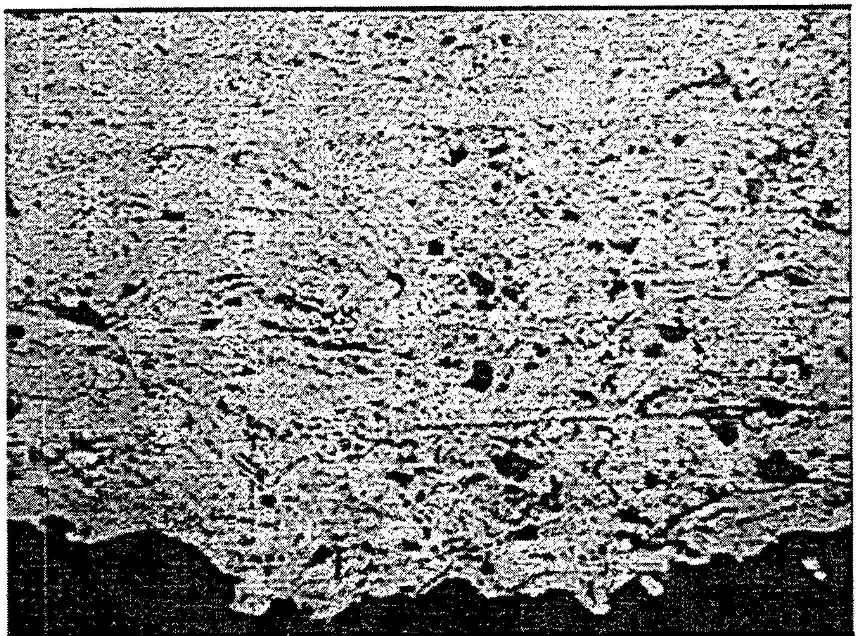

PHOTO 1 TAKEN AT 200X

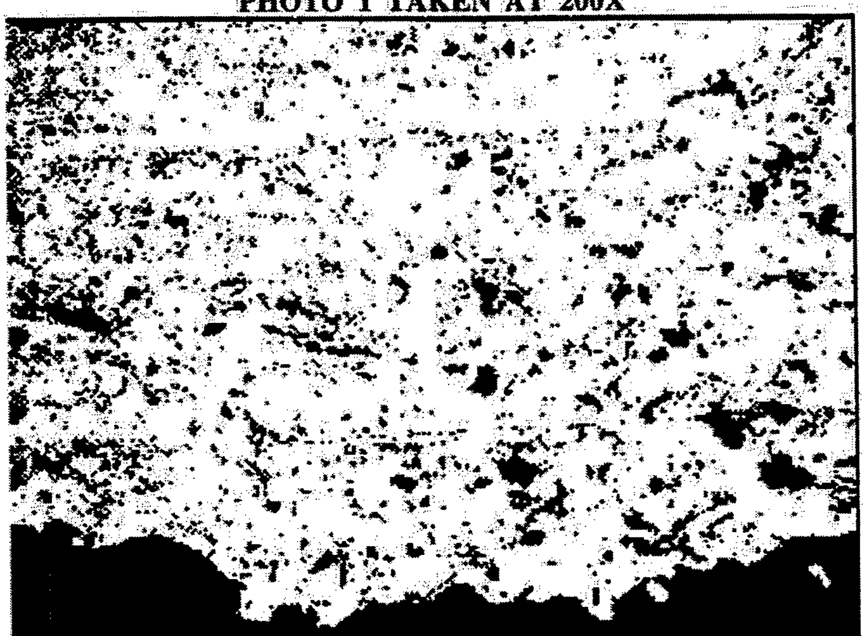

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-20Z

Figure E20. Photomicrograph of Coating Z20 (1/8" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

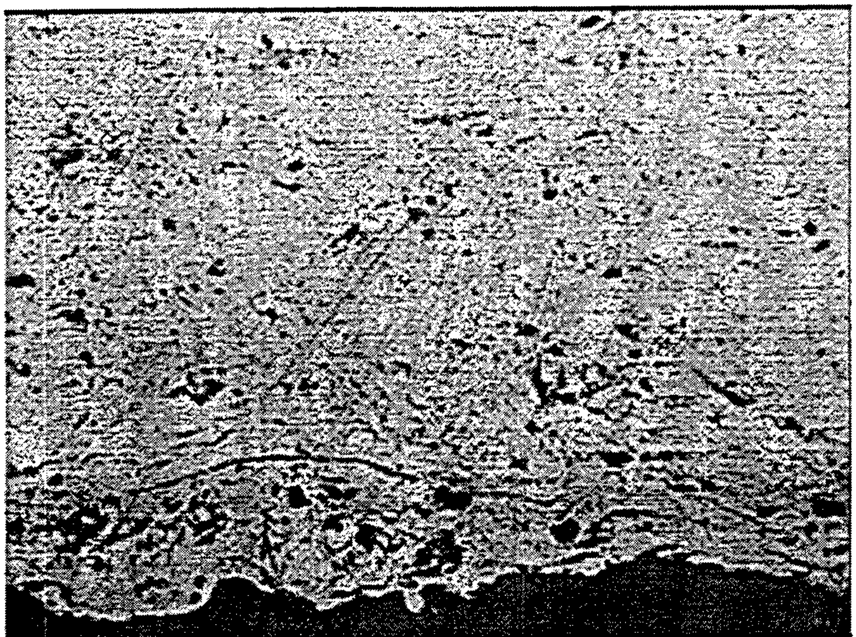

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-21Z

Figure E21. Photomicrograph of Coating Z21 (1/8" zinc)

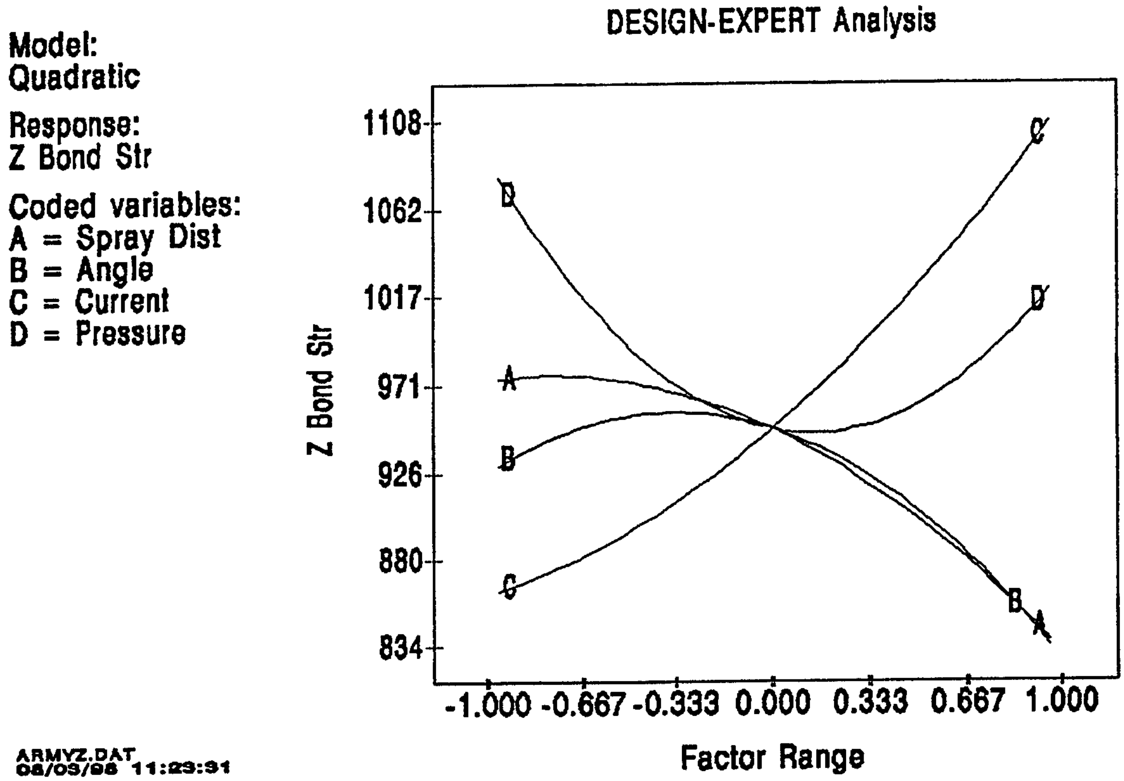

Figure E22. Bond Strength Parameter Plot for 1/8" Zn Coatings

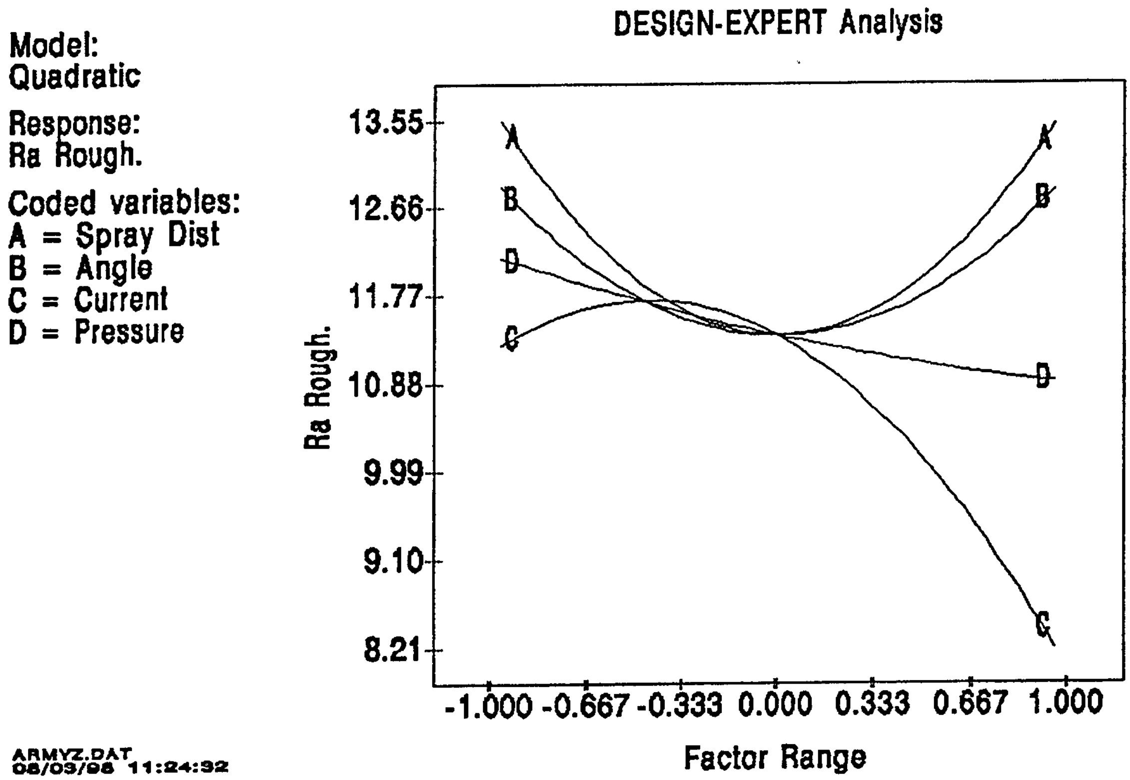

Figure E23. Roughness Parameter Plot for 1/8" Zn Coatings

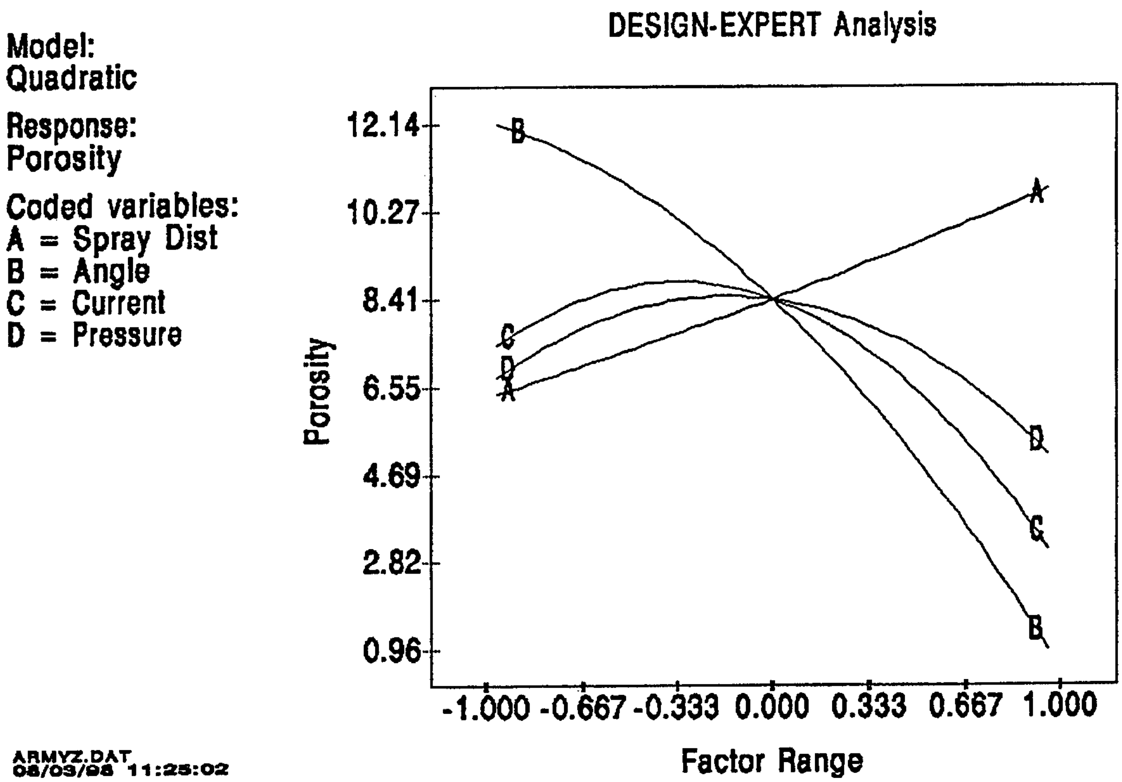

Figure E24. Porosity Parameter Plot for 1/8" Zn Coatings

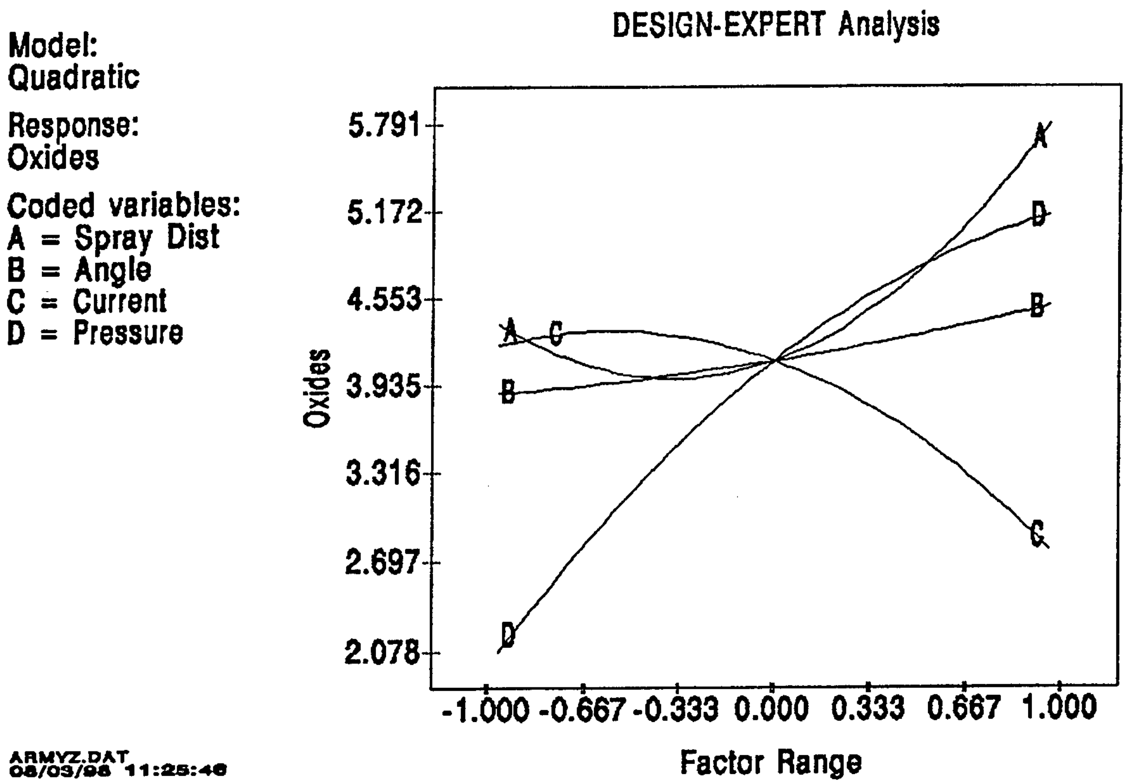

Figure E25. Oxides Parameter Plot for 1/8" Zn Coatings

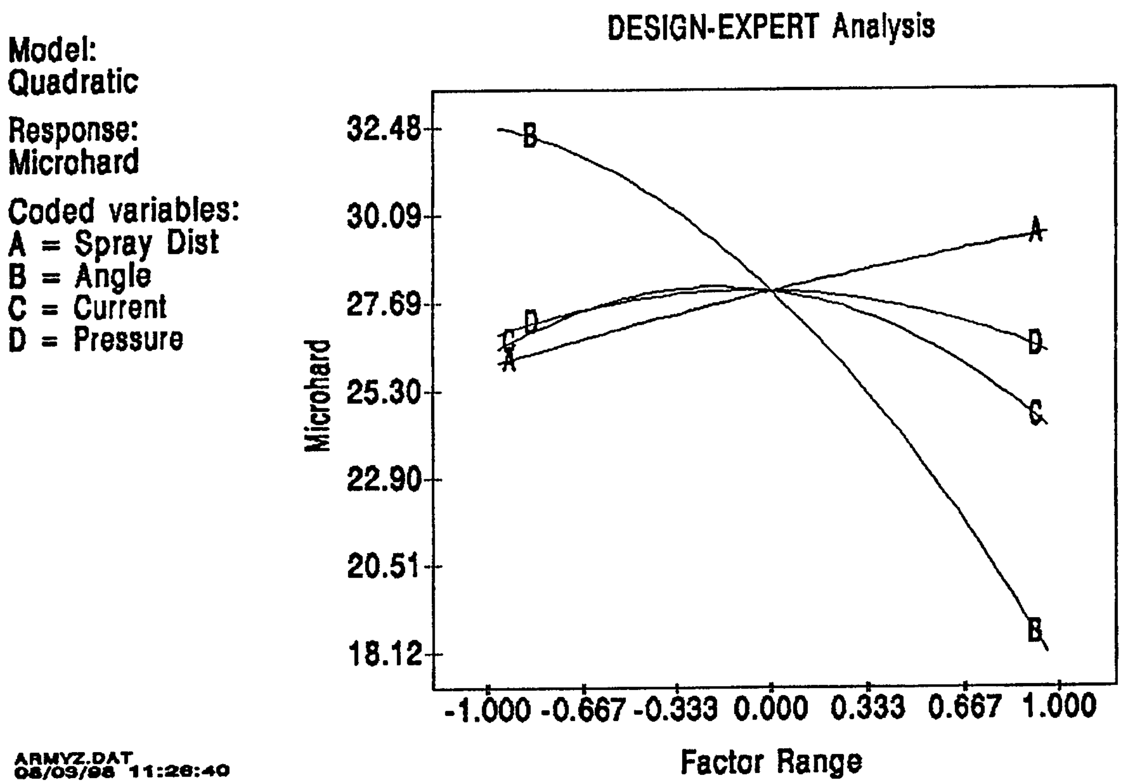

Figure E26. Hardness Parameter Plot for 1/8" Zn Coatings

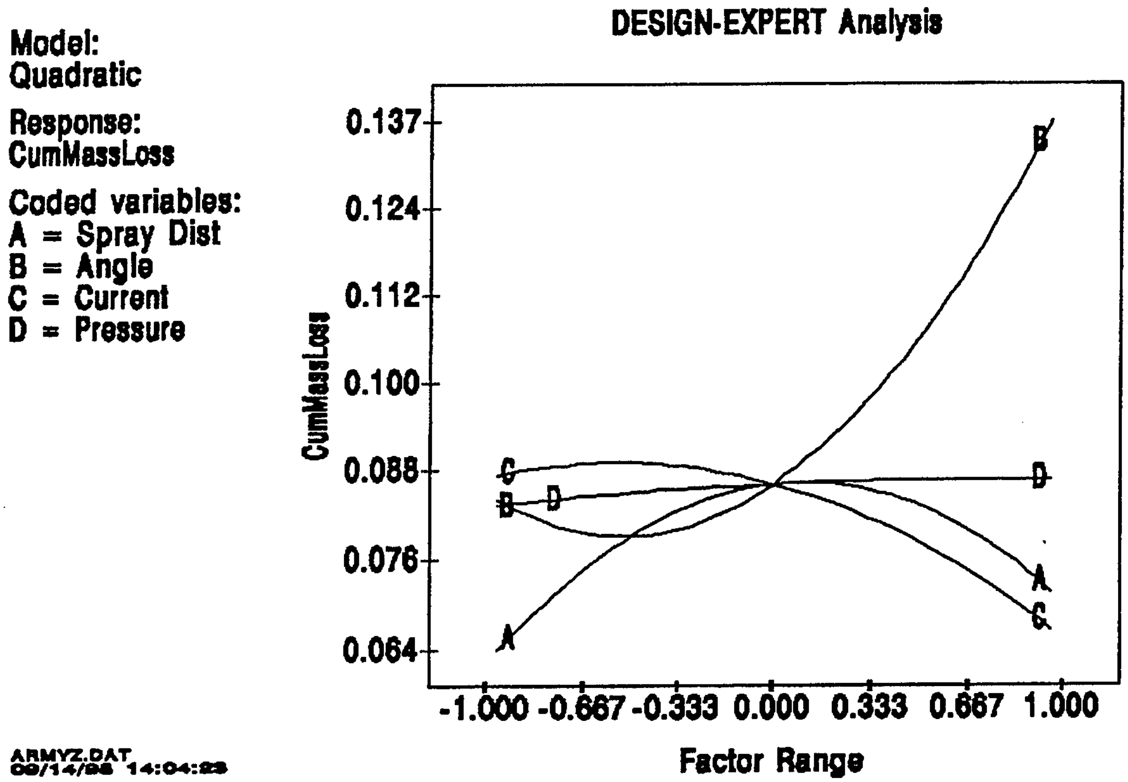

Figure E27. CML Parameter Plot for 1/8" Zn Coatings

Table E1. 1/8" Zinc Statistical Analysis of Bond Strength

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	18868992.2	1	18868992.2		
Linear	141659.0	4	35414.8	3.743	0.0247
Quadratic	147887.9	10	14788.8	25.33	0.0004
Cubic	2542.1	2	1271.1	5.292	0.0752
RESIDUAL	960.8	4	240.2		
TOTAL	19162042.0	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	150430.1	12	12535.8	52.19	0.0008
Quadratic	2542.1	2	1271.1	5.292	0.0752
Cubic	0.0	0			
PURE ERR	960.8	4	240.2		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	97.3	0.4834	0.3542	316351.0
Quadratic	15	6	24.2	0.9880	0.9602	531090.6
Cubic	17	4	15.5	0.9967	0.9836	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	289546.9	14	20681.9	35.43	0.0001
RESIDUAL	3502.9	6	583.8		
Lack Of Fit	2542.1	2	1271.1	5.292	0.0752
Pure Error	960.8	4	240.2		
COR TOTAL	293049.8	20			

ROOT MSE	24.2	R-SQUARED	0.9880
DEP MEAN	947.9	ADJ R-SQUARED	0.9602
C.V.	2.55%		

Predicted Residual Sum of Squares (PRESS) = 531090.6

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	948.7	1	9.1	104.6	
A	-71.4	1	14.3	-4.988	0.0025
B	-49.6	1	44.8	-1.107	0.3108
C	127.0	1	17.1	7.433	0.0003
D	-30.5	1	17.1	-1.785	0.1245
A2	-46.2	1	14.3	-3.220	0.0181
B2	-72.2	1	24.5	-2.948	0.0257
C2	40.4	1	13.9	2.903	0.0272
D2	109.9	1	13.2	8.331	0.0002
AB	-78.4	1	32.7	-2.392	0.0538

CD	193.8	1	36.8	5.265	0.0019

Final Equation in Terms of Actual Factors:

```
Z Bond Str =
                 21028.5
      -           268.04 * Spray Dist
      +           33.047 * Angle
      -           20.385 * Current
      -           333.14 * Pressure
      -           5.1340 * Spray Dist^2
      -          0.14264 * Angle      ^2
      +        4.040E-03 * Current^2
      +           1.0991 * Pressure^2
      -           1.1608 * Spray Dist * Angle
      -          0.39326 * Spray Dist * Current
      +           5.7876 * Spray Dist * Pressure
      +        3.315E-02 * Angle        * Current
      -          0.10734 * Angle        * Pressure
      +          0.19383 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	1223.0	1226.6	-3.6	0.980	-1.069	3.752	-1.084	1
2	978.0	973.9	4.1	0.492	0.241	0.004	0.221	2
3	917.0	911.6	5.4	0.986	1.860	16.010	2.609	3
4	1008.0	1029.6	-21.6	0.751	-1.793	0.646	-2.403	4
5	1059.0	1062.6	-3.6	0.980	-1.069	3.752	-1.084	5
6	836.0	821.6	14.4	0.919	2.085	3.279	3.623	6
7	876.0	861.6	14.4	0.919	2.085	3.279	3.623	7
8	927.0	921.6	5.4	0.986	1.860	16.010	2.609	8
9	713.0	716.6	-3.6	0.980	-1.069	3.752	-1.084	9
10	968.0	973.9	-5.9	0.492	-0.340	0.007	-0.313	10
11	958.0	948.7	9.3	0.141	0.417	0.002	0.386	11
12	815.0	831.1	-16.1	0.872	-1.860	1.574	-2.609	12
13	937.0	926.1	10.9	0.821	1.069	0.349	1.084	13
14	948.0	948.7	-0.7	0.141	-0.030	0.000	-0.027	14
15	743.0	759.1	-16.1	0.872	-1.860	1.574	-2.609	15
16	846.0	862.1	-16.1	0.872	-1.860	1.574	-2.609	16
17	937.0	948.7	-11.7	0.141	-0.521	0.003	-0.487	17
18	1100.0	1116.1	-16.1	0.872	-1.860	1.574	-2.609	18
19	1100.0	1089.1	10.9	0.821	1.069	0.349	1.084	19
20	978.0	948.7	29.3	0.141	1.310	0.019	1.415	20
21	1039.0	1028.1	10.9	0.821	1.069	0.349	1.084	21

Table E2. 1/8" Zinc Statistical Analysis of CML

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	0.146818	1	0.146818		
Linear	0.002672	4	0.000668	2.667	0.0705
Quadratic	0.002770	10	0.000277	1.344	0.3726
Cubic	0.000582	2	0.000291	1.775	0.2807
RESIDUAL	0.000655	4	0.000164		
TOTAL	0.153497	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	0.003352	12	0.000279	1.705	0.3214
Quadratic	0.000582	2	0.000291	1.775	0.2807
Cubic	0.000000	0			
PURE ERR	0.000655	4	0.000164		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	0.01583	0.4000	0.2500	0.00748
Quadratic	15	6	0.01436	0.8148	0.3827	0.12167
Cubic	17	4	0.01280	0.9019	0.5094	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	0.005442	14	0.00039	1.886	0.2235
RESIDUAL	0.001237	6	0.00021		
Lack Of Fit	0.000582	2	0.00029	1.775	0.2807
Pure Error	0.000655	4	0.00016		
COR TOTAL	0.006678	20			

ROOT MSE	0.01436	R-SQUARED	0.8148
DEP MEAN	0.08361	ADJ R-SQUARED	0.3827
C.V.	17.17%		

Predicted Residual Sum of Squares (PRESS) = 0.121667

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	0.08608	1	0.00539	15.97	
A	0.00414	1	0.00850	0.4870	0.6436
B	0.02732	1	0.02664	1.026	0.3446
C	-0.01085	1	0.01015	-1.069	0.3263
D	0.00170	1	0.01015	0.1675	0.8725
A2	-0.02004	1	0.00853	-2.350	0.0571
B2	0.02629	1	0.01455	1.806	0.1209
C2	-0.00995	1	0.00827	-1.203	0.2743
D2	-0.00124	1	0.00784	-0.1576	0.8799

Table E2. 1/8" Zinc Statistical Analysis of CML

AC	0.02689	1	0.02043	1.316	0.2362
AD	0.01757	1	0.02208	0.7955	0.4566
BC	-0.02178	1	0.00954	-2.284	0.0624
BD	0.01144	1	0.01480	0.7729	0.4689
CD	-0.01440	1	0.02188	-0.6581	0.5349

Final Equation in Terms of Actual Factors:

CumMassLoss =

```
          0.52931
    -     5.861E-02 * Spray Dist
    -     1.084E-02 * Angle
    +     2.092E-03 * Current
    -     2.164E-03 * Pressure
    -     2.226E-03 * Spray Dist^2
    +     5.193E-05 * Angle      ^2
    -     9.945E-07 * Current^2
    -     1.236E-05 * Pressure^2
    +     1.127E-04 * Spray Dist * Angle
    +     8.962E-05 * Spray Dist * Current
    +     5.856E-04 * Spray Dist * Pressure
    -     9.682E-06 * Angle        * Current
    +     5.082E-05 * Angle        * Pressure
    -     1.440E-05 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	0.08740	0.08615	0.00125	0.980	0.617	1.251	0.582	1
2	0.08040	0.06191	0.01849	0.492	1.807	0.211	2.444	2
3	0.06640	0.06914	-0.00274	0.986	-1.600	11.849	-1.929	3
4	0.08330	0.07408	0.00922	0.751	1.287	0.332	1.380	4
5	0.07800	0.07675	0.00125	0.980	0.617	1.251	0.582	5
6	0.08720	0.09392	-0.00672	0.919	-1.644	2.038	-2.024	6
7	0.08270	0.08942	-0.00672	0.919	-1.644	2.038	-2.024	7
8	0.07390	0.07664	-0.00274	0.986	-1.600	11.849	-1.929	8
9	0.10910	0.10785	0.00125	0.980	0.617	1.251	0.582	9
10	0.04490	0.06191	-0.01701	0.492	-1.662	0.178	-2.065	10
11	0.07790	0.08608	-0.00818	0.141	-0.615	0.004	-0.580	11
12	0.07840	0.07019	0.00821	0.872	1.600	1.165	1.929	12
13	0.08130	0.08505	-0.00375	0.821	-0.617	0.116	-0.582	13
14	0.08490	0.08608	-0.00118	0.141	-0.089	0.000	-0.081	14
15	0.14480	0.13659	0.00821	0.872	1.600	1.165	1.929	15
16	0.09520	0.08699	0.00821	0.872	1.600	1.165	1.929	16
17	0.08220	0.08608	-0.00388	0.141	-0.292	0.001	-0.268	17
18	0.07350	0.06529	0.00821	0.872	1.600	1.165	1.929	18
19	0.07940	0.08315	-0.00375	0.821	-0.617	0.116	-0.582	19
20	0.08220	0.08608	-0.00388	0.141	-0.292	0.001	-0.268	20
21	0.08280	0.08655	-0.00375	0.821	-0.617	0.116	-0.582	21

Table E3. 1/8" Zinc Statistical Analysis of Microhardness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	16107.6	1	16107.6		
Linear	61.2	4	15.3	1.944	0.1521
Quadratic	67.3	10	6.7	0.6892	0.7129
Cubic	33.9	2	17.0	2.750	0.1772
RESIDUAL	24.7	4	6.2		
TOTAL	16294.7	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	101.2	12	8.4	1.368	0.4121
Quadratic	33.9	2	17.0	2.750	0.1772
Cubic	0.0	0			
PURE ERR	24.7	4	6.2		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	2.81	0.3270	0.1588	196.01
Quadratic	15	6	3.13	0.6868	-0.0440	5629.80
Cubic	17	4	2.48	0.8681	0.3407	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	128.5	14	9.18	0.9398	0.5719
RESIDUAL	58.6	6	9.77		
Lack Of Fit	33.9	2	16.97	2.750	0.1772
Pure Error	24.7	4	6.17		
COR TOTAL	187.1	20			

ROOT MSE	3.13	R-SQUARED	0.6868
DEP MEAN	27.70	ADJ R-SQUARED	-0.0440
C.V.	11.28%		

Predicted Residual Sum of Squares (PRESS) = 5629.8

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	28.05	1	1.17	23.91	
A	1.86	1	1.85	1.002	0.3548
B	-7.48	1	5.80	-1.290	0.2445
C	-1.10	1	2.21	-0.4978	0.6364
D	-0.25	1	2.21	-0.1131	0.9136
A2	-0.25	1	1.86	-0.1326	0.8988
B2	-2.99	1	3.17	-0.9434	0.3819
C2	-2.89	1	1.80	-1.606	0.1594
D2	-1.56	1	1.71	-0.9120	0.3969

BD	1.08	1	3.22	0.3352	0.7489
CD	-1.09	1	4.76	-0.2297	0.8260

Final Equation in Terms of Actual Factors:

Microhard =

```
             -251.43
  +           9.5450 * Spray Dist
  +        3.025E-02 * Angle
  +          0.38231 * Current
  +           3.6725 * Pressure
  -        2.735E-02 * Spray Dist^2
  -        5.904E-03 * Angle      ^2
  -        2.890E-04 * Current^2
  -        1.556E-02 * Pressure^2
  +        2.214E-02 * Spray Dist * Angle
  -        9.662E-03 * Spray Dist * Current
  -        7.045E-02 * Spray Dist * Pressure
  +        5.937E-05 * Angle        * Current
  +        4.799E-03 * Angle        * Pressure
  -        1.094E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	24.40	23.95	0.45	0.980	1.019	3.411	1.023	1
2	27.10	25.95	1.15	0.492	0.515	0.017	0.481	2
3	28.20	27.65	0.55	0.986	1.489	10.262	1.712	3
4	29.90	29.66	0.24	0.751	0.153	0.005	0.140	4
5	24.30	23.85	0.45	0.980	1.019	3.411	1.023	5
6	30.20	29.54	0.66	0.919	0.741	0.414	0.710	6
7	26.30	25.64	0.66	0.919	0.741	0.414	0.710	7
8	28.50	27.95	0.55	0.986	1.489	10.262	1.712	8
9	33.10	32.65	0.45	0.980	1.019	3.411	1.023	9
10	23.80	25.95	-2.15	0.492	-0.966	0.060	-0.960	10
11	31.10	28.05	3.05	0.141	1.052	0.012	1.063	11
12	28.00	29.66	-1.66	0.872	-1.489	1.009	-1.712	12
13	31.20	32.55	-1.35	0.821	-1.019	0.317	-1.023	13
14	26.50	28.05	-1.55	0.141	-0.536	0.003	-0.502	14
15	29.40	31.06	-1.66	0.872	-1.489	1.009	-1.712	15
16	24.60	26.26	-1.66	0.872	-1.489	1.009	-1.712	16
17	32.40	28.05	4.35	0.141	1.500	0.025	1.733	17
18	22.40	24.06	-1.66	0.872	-1.489	1.009	-1.712	18
19	25.40	26.75	-1.35	0.821	-1.019	0.317	-1.023	19
20	29.90	28.05	1.85	0.141	0.637	0.004	0.603	20
21	24.90	26.25	-1.35	0.821	-1.019	0.317	-1.023	21

Table E4. 1/8" Zinc Statistical Analysis of Oxides

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	328.05	1	328.05		
Linear	15.59	4	3.90	1.043	0.4159
Quadratic	27.41	10	2.74	0.5080	0.8358
Cubic	10.25	2	5.12	0.9261	0.4672
RESIDUAL	22.13	4	5.53		
TOTAL	403.42	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	37.66	12	3.14	0.5673	0.7989
Quadratic	10.25	2	5.12	0.9261	0.4672
Cubic	0.00	0			
PURE ERR	22.13	4	5.53		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	1.933	0.2068	0.0085	109.988
Quadratic	15	6	2.323	0.5705	-0.4317	1874.753
Cubic	17	4	2.352	0.7064	-0.4679	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	43.00	14	3.071	0.5692	0.8196
RESIDUAL	32.37	6	5.396		
Lack Of Fit	10.25	2	5.123	0.9261	0.4672
Pure Error	22.13	4	5.532		
COR TOTAL	75.37	20			

ROOT MSE	2.323	R-SQUARED	0.5705
DEP MEAN	3.952	ADJ R-SQUARED	-0.4317
C.V.	58.77%		

Predicted Residual Sum of Squares (PRESS) = 1874.75

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	4.112	1	0.872	4.715	
A	0.737	1	1.376	0.5356	0.6115
B	0.325	1	4.310	7.54E-02	0.9423
C	-0.750	1	1.642	-0.4566	0.6640
D	1.600	1	1.642	0.9741	0.3676
A2	1.054	1	1.379	0.7643	0.4736
B2	0.085	1	2.355	3.62E-02	0.9723
C2	-0.659	1	1.338	-0.4925	0.6399
D2	-0.540	1	E35 1.268	-0.4255	0.6853

BD	2.069	1	2.394	0.8643	0.4206
CD	-0.746	1	3.539	-0.2108	0.8400

Final Equation in Terms of Actual Factors:

Oxides =

```
          -53.453
+           2.2229 * Spray Dist
-          0.98335 * Angle
+          0.15585 * Current
+           1.1219 * Pressure
+          0.11715 * Spray Dist^2
+        1.685E-04 * Angle      ^2
-        6.587E-05 * Current^2
-        5.397E-03 * Pressure^2
+        1.689E-02 * Spray Dist * Angle
-        1.762E-03 * Spray Dist * Current
-        4.989E-02 * Spray Dist * Pressure
-        2.975E-04 * Angle        * Current
+        9.196E-03 * Angle        * Pressure
-        7.460E-04 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	2.000	1.909	0.091	0.980	0.277	0.252	0.254	1
2	3.700	4.429	-0.729	0.492	-0.440	0.013	-0.409	2
3	4.900	4.532	0.368	0.986	1.328	8.168	1.443	3
4	2.400	2.863	-0.463	0.751	-0.399	0.032	-0.370	4
5	1.400	1.309	0.091	0.980	0.277	0.252	0.254	5
6	3.200	2.555	0.645	0.919	0.974	0.716	0.969	6
7	3.900	3.255	0.645	0.919	0.974	0.716	0.969	7
8	7.200	6.832	0.368	0.986	1.328	8.168	1.443	8
9	6.900	6.809	0.091	0.980	0.277	0.252	0.254	9
10	4.700	4.429	0.271	0.492	0.164	0.002	0.150	10
11	7.900	4.112	3.788	0.141	1.760	0.034	2.309	11
12	4.800	5.903	-1.103	0.872	-1.328	0.803	-1.443	12
13	3.600	3.872	-0.272	0.821	-0.277	0.023	-0.254	13
14	2.400	4.112	-1.712	0.141	-0.795	0.007	-0.767	14
15	2.700	3.803	-1.103	0.872	-1.328	0.803	-1.443	15
16	3.100	4.203	-1.103	0.872	-1.328	0.803	-1.443	16
17	6.800	4.112	2.688	0.141	1.249	0.017	1.325	17
18	1.600	2.703	-1.103	0.872	-1.328	0.803	-1.443	18
19	1.700	1.972	-0.272	0.821	-0.277	0.023	-0.254	19
20	3.200	4.112	-0.912	0.141	-0.423	0.002	-0.393	20
21	4.900	5.172	-0.272	0.821	-0.277	0.023	-0.254	21

Table E5. 1/8" Zinc Statistical Analysis of Porosity

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	1199.3	1	1199.3		
Linear	92.6	4	23.2	1.974	0.1471
Quadratic	151.8	10	15.2	2.540	0.1330
Cubic	19.9	2	9.9	2.485	0.1989
RESIDUAL	16.0	4	4.0		
TOTAL	1479.7	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	171.7	12	14.3	3.579	0.1143
Quadratic	19.9	2	9.9	2.485	0.1989
Cubic	0.0	0			
PURE ERR	16.0	4	4.0		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	3.42	0.3305	0.1631	369.10
Quadratic	15	6	2.44	0.8721	0.5736	3994.88
Cubic	17	4	2.00	0.9430	0.7148	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	244.5	14	17.46	2.921	0.0971
RESIDUAL	35.9	6	5.98		
Lack Of Fit	19.9	2	9.94	2.485	0.1989
Pure Error	16.0	4	4.00		
COR TOTAL	280.3	20			

ROOT MSE	2.44	R-SQUARED	0.8721
DEP MEAN	7.56	ADJ R-SQUARED	0.5736
C.V.	32.35%		

Predicted Residual Sum of Squares (PRESS) = 3994.9

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	8.44	1	0.92	9.193	
A	2.26	1	1.45	1.564	0.1689
B	-5.82	1	4.54	-1.283	0.2469
C	-2.25	1	1.73	-1.302	0.2408
D	-0.85	1	1.73	-0.4917	0.6404
A2	0.17	1	1.45	0.1200	0.9084
B2	-2.05	1	2.48	-0.8272	0.4398

AD	-3.00	1	3.76	-0.7981	0.4552
BC	-1.55	1	1.62	-0.9541	0.3769
BD	2.63	1	2.52	1.045	0.3362
CD	-1.98	1	3.73	-0.5325	0.6135

Final Equation in Terms of Actual Factors:

```
      Porosity =
                      -390.51
          +            12.069 * Spray Dist
          -           0.71412 * Angle
          +           0.58480 * Current
          +            5.8172 * Pressure
          +         1.936E-02 * Spray Dist^2
          -         4.049E-03 * Angle       ^2
          -         3.411E-04 * Current^2
          -         2.680E-02 * Pressure^2
          +         2.832E-02 * Spray Dist * Angle
          -         1.202E-02 * Spray Dist * Current
          -           0.10005 * Spray Dist * Pressure
          -         6.886E-04 * Angle        * Current
          +         1.170E-02 * Angle        * Pressure
          -         1.984E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	1.40	1.53	-0.13	0.980	-0.379	0.472	-0.350	1
2	4.50	6.35	-1.85	0.492	-1.060	0.073	-1.074	2
3	7.40	6.87	0.53	0.986	1.805	15.078	2.437	3
4	4.60	6.04	-1.44	0.751	-1.183	0.281	-1.233	4
5	2.80	2.93	-0.13	0.980	-0.379	0.472	-0.350	5
6	8.80	7.62	1.18	0.919	1.697	2.174	2.149	6
7	6.20	5.02	1.18	0.919	1.697	2.174	2.149	7
8	9.30	8.77	0.53	0.986	1.805	15.078	2.437	8
9	16.80	16.93	-0.13	0.980	-0.379	0.472	-0.350	9
10	7.80	6.35	1.45	0.492	0.834	0.045	0.809	10
11	7.90	8.44	-0.54	0.141	-0.237	0.001	-0.218	11
12	9.30	10.88	-1.58	0.872	-1.805	1.482	-2.437	12
13	12.60	12.21	0.39	0.821	0.379	0.044	0.350	13
14	8.40	8.44	-0.04	0.141	-0.017	0.000	-0.015	14
15	10.30	11.88	-1.58	0.872	-1.805	1.482	-2.437	15
16	5.70	7.28	-1.58	0.872	-1.805	1.482	-2.437	16
17	12.10	8.44	3.66	0.141	1.616	0.029	1.963	17
18	1.20	2.78	-1.58	0.872	-1.805	1.482	-2.437	18
19	7.00	6.61	0.39	0.821	0.379	0.044	0.350	19
20	9.30	8.44	0.86	0.141	0.380	0.002	0.351	20
21	5.30	4.91	0.39	0.821	0.379	0.044	0.350	21

Table E6. 1/8" Zinc Statistical Analysis of Roughness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	3659.3	1	3659.3		
Linear	81.1	4	20.3	5.100	0.0076
Quadratic	50.6	10	5.1	2.338	0.1553
Cubic	6.6	2	3.3	2.090	0.2392
RESIDUAL	6.4	4	1.6		
TOTAL	3804.1	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	57.3	12	4.8	3.004	0.1494
Quadratic	6.6	2	3.3	2.090	0.2392
Cubic	0.0	0			
PURE ERR	6.4	4	1.6		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	1.99	0.5604	0.4505	111.58
Quadratic	15	6	1.47	0.9102	0.7008	1223.87
Cubic	17	4	1.26	0.9561	0.7805	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	131.8	14	9.41	4.346	0.0402
RESIDUAL	13.0	6	2.17		
Lack Of Fit	6.6	2	3.32	2.090	0.2392
Pure Error	6.4	4	1.59		
COR TOTAL	144.8	20			

ROOT MSE	1.47	R-SQUARED	0.9102
DEP MEAN	13.20	ADJ R-SQUARED	0.7008
C.V.	11.15%		

Predicted Residual Sum of Squares (PRESS) = 1223.9

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	11.38	1	0.55	20.59	
A	-0.02	1	0.87	-2.18E-02	0.9833
B	-0.01	1	2.73	-5.14E-03	0.9961
C	-1.59	1	1.04	-1.533	0.1762
D	-0.66	1	1.04	-0.6343	0.5493
A2	2.34	1	0.87	2.682	0.0364
B2	1.61	1	1.49	1.079	0.3222
C2	-1.77	1	0.85	-2.089	0.0817
D2	0.17	1	E39 0.80	0.2156	0.8365

BD	-0.96	1	1.52	-0.6327	0.5503
CD	-6.98	1	2.24	-3.113	0.0208

Final Equation in Terms of Actual Factors:

Ra Rough. =

```
                 -244.82
        -         2.3444 * Spray Dist
        -        0.35219 * Angle
        +        0.66597 * Current
        +         3.4440 * Pressure
        +        0.26041 * Spray Dist^2
        +      3.179E-03 * Angle       ^2
        -      1.770E-04 * Current^2
        +      1.732E-03 * Pressure^2
        +      3.168E-02 * Spray Dist * Angle
        +      1.782E-02 * Spray Dist * Current
        -        0.11439 * Spray Dist * Pressure
        -      2.264E-04 * Angle        * Current
        -      4.265E-03 * Angle        * Pressure
        -      6.980E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	11.57	11.62	-0.05	0.980	-0.259	0.220	-0.238	1
2	14.70	13.74	0.96	0.492	0.917	0.054	0.903	2
3	14.37	14.67	-0.30	0.986	-1.710	13.542	-2.181	3
4	13.91	13.47	0.44	0.751	0.597	0.072	0.562	4
5	15.77	15.82	-0.05	0.980	-0.259	0.220	-0.238	5
6	16.10	16.65	-0.55	0.919	-1.302	1.280	-1.404	6
7	15.13	15.68	-0.55	0.919	-1.302	1.280	-1.404	7
8	10.94	11.24	-0.30	0.986	-1.710	13.542	-2.181	8
9	18.18	18.23	-0.05	0.980	-0.259	0.220	-0.238	9
10	13.13	13.74	-0.61	0.492	-0.580	0.022	-0.545	10
11	12.39	11.38	1.01	0.141	0.744	0.006	0.713	11
12	14.60	13.70	0.90	0.872	1.710	1.331	2.181	12
13	13.16	13.00	0.16	0.821	0.259	0.021	0.238	13
14	10.18	11.38	-1.20	0.141	-0.876	0.008	-0.857	14
15	18.74	17.84	0.90	0.872	1.710	1.331	2.181	15
16	12.10	11.20	0.90	0.872	1.710	1.331	2.181	16
17	10.63	11.38	-0.75	0.141	-0.547	0.003	-0.512	17
18	8.91	8.01	0.90	0.872	1.710	1.331	2.181	18
19	12.37	12.21	0.16	0.821	0.259	0.021	0.238	19
20	9.28	11.38	-2.10	0.141	-1.536	0.026	-1.801	20
21	11.05	10.89	0.16	0.821	0.259	0.021	0.238	21

Table E7. Minitab Analysis for 1/8" Zinc

```
MTB > regress c6 10 c1-c5 c12-c16;
SUBC> residuals c22.
```

The regression equation is

CML = - 1.22 +0.000616 BS + 0.00492 R - 0.00435 P - 0.00167 O + 0.0006 MH + 623 1/BS + 1.21 1/R - 0.0600 1/P + 0.0184 1/O - 2.1 1/MH

Predictor	Coef	Stdev	t-ratio	p
Constant	-1.2226	0.9730	-1.26	0.237
BS	0.0006161	0.0002168	2.84	0.018
R	0.004919	0.007848	0.63	0.545
P	-0.004348	0.002497	-1.74	0.112
O	-0.001670	0.003367	-0.50	0.631
MH	0.00062	0.01477	0.04	0.968
1/BS	623.0	198.2	3.14	0.010
1/R	1.209	1.154	1.05	0.320
1/P	-0.06003	0.04477	-1.34	0.210
1/O	0.01841	0.04489	0.41	0.690
1/MH	-2.11	10.83	-0.19	0.849

s = 0.01152   R-sq = 80.1%   R-sq(adj) = 60.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	10	0.0053511	0.0005351	4.03	0.019
Error	10	0.0013274	0.0001327		
Total	20	0.0066785			

SOURCE	DF	SEQ SS
BS	1	0.0015629
R	1	0.0004470
P	1	0.0000013
O	1	0.0006314
MH	1	0.0003627
1/BS	1	0.0018119
1/R	1	0.0000292
1/P	1	0.0004816
1/O	1	0.0000181
1/MH	1	0.0000050

RESIDUALS:

0.0002723	0.0041962	-0.0079718	-0.0069523	0.0003205	-0.0087849
0.0025753	0.0018585	-0.0084041	-0.0095745	0.0029691	-0.0109436
0.0140129	0.0007624	0.0164558	0.0059441	0.0080187	-0.0006612
-0.0021822	-0.0120287	0.0101174			

Appendix F. Results for the 3/16" Zinc Wire System

Figures F1-F21: Photomicrographs F1-F21
Figures F22-F27: Perturbation Plots
Tables F1-F6: Design Expert Analysis
Table F7: Minitab Analysis

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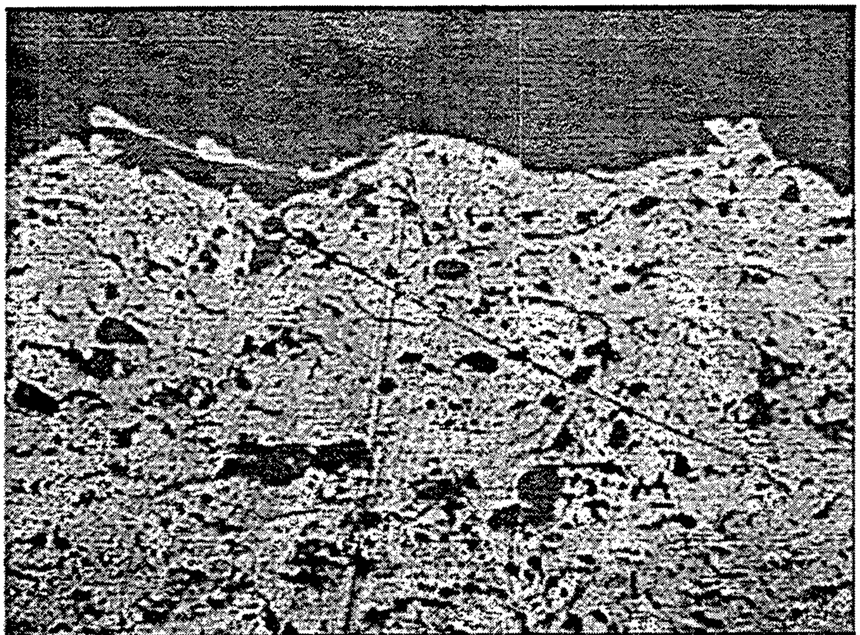

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-1BZ

Figure F1. Photomicrograph of Coating BZ1 (3/16" zinc)

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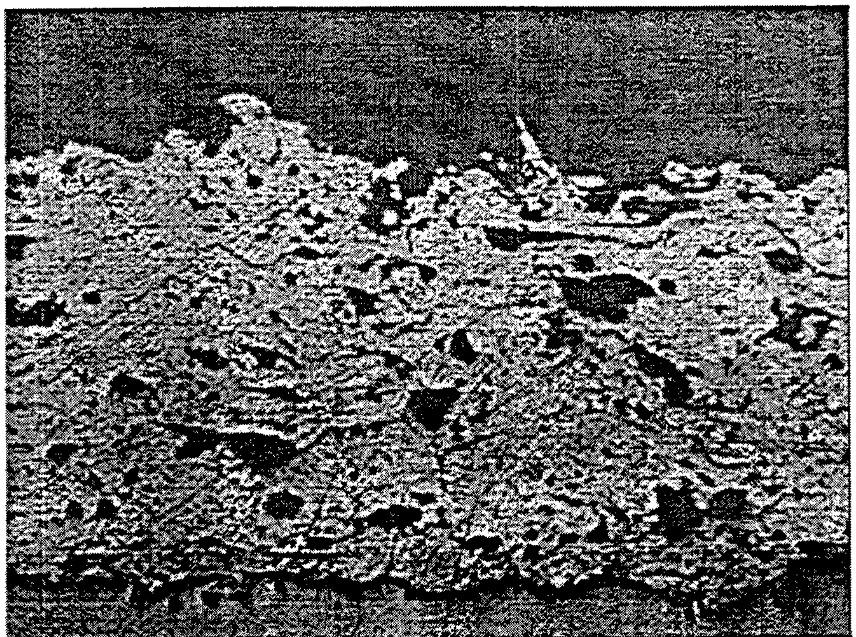

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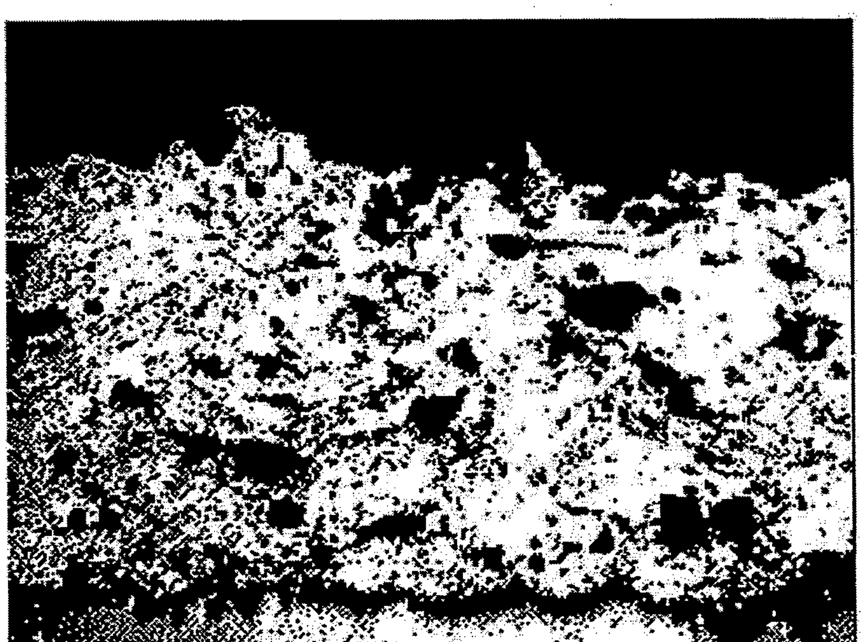

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-2BZ

Figure F2. Photomicrograph of Coating BZ2 (3/16" zinc)

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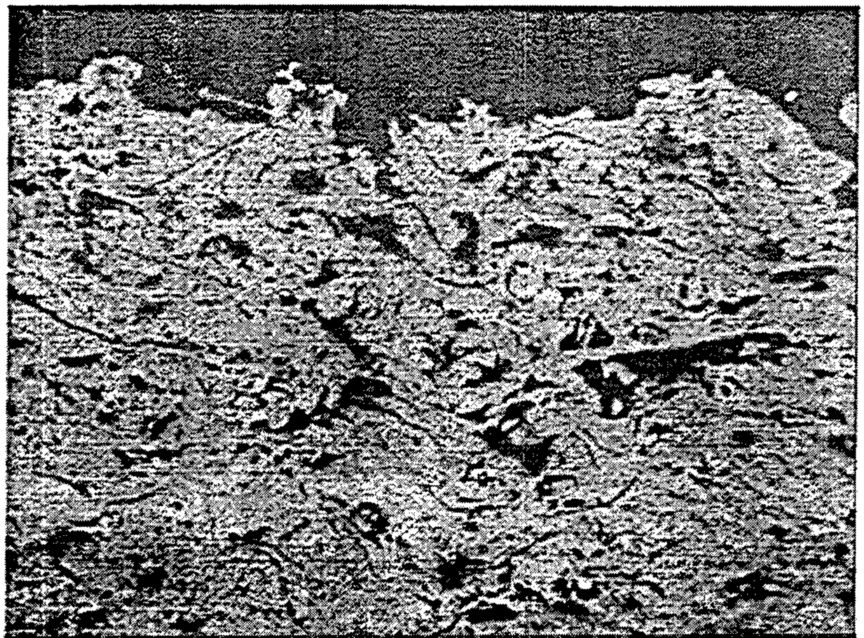

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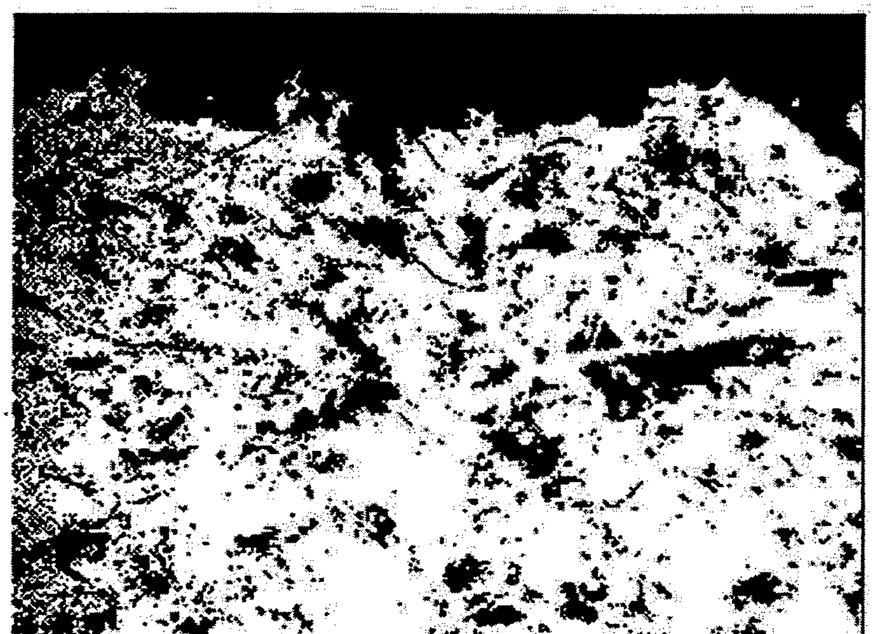

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-3BZ

Figure F3. Photomicrograph of Coating BZ3 (3/16" zinc)

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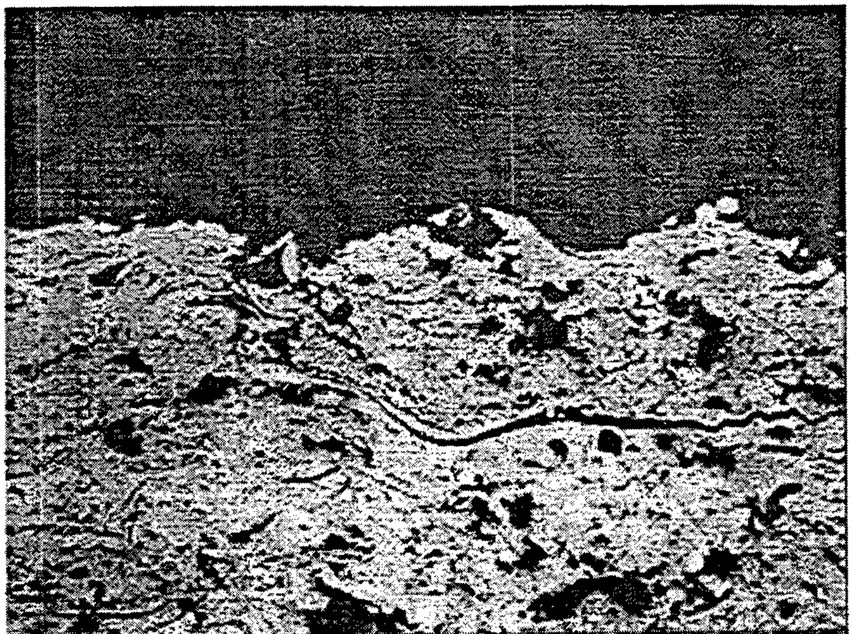

PHOTO 1 TAKEN AT 200X

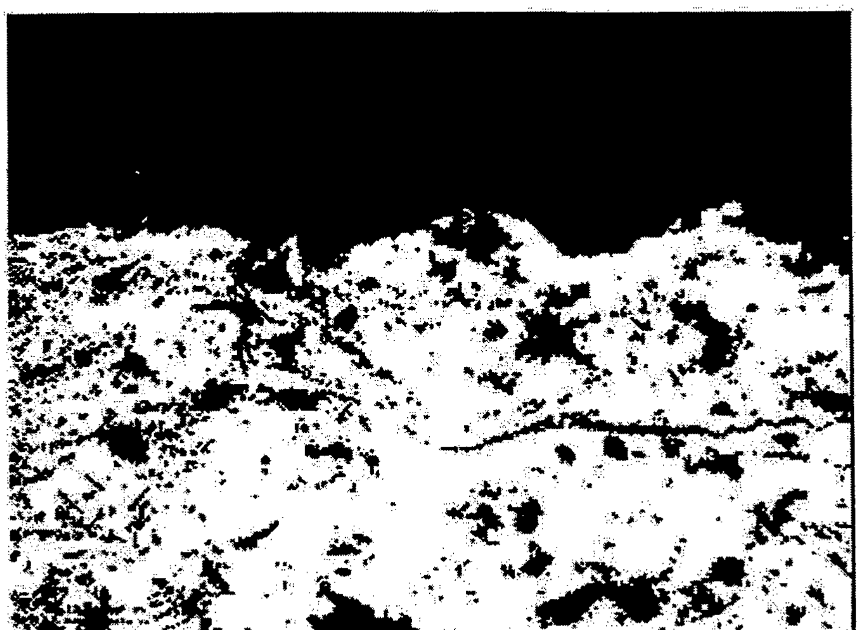

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-4BZ

Figure F4. Photomicrograph of Coating BZ4 (3/16" zinc)

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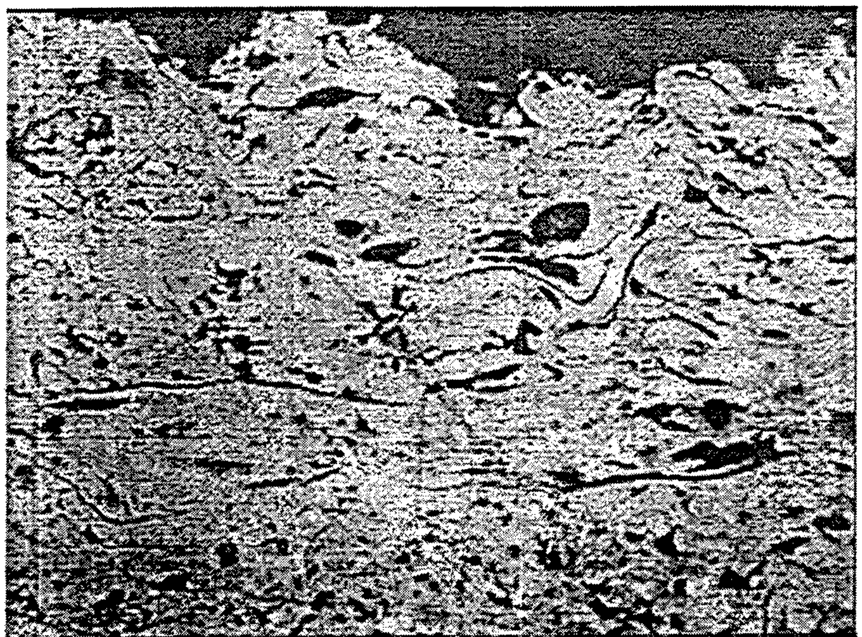

PHOTO 1 TAKEN AT 200X

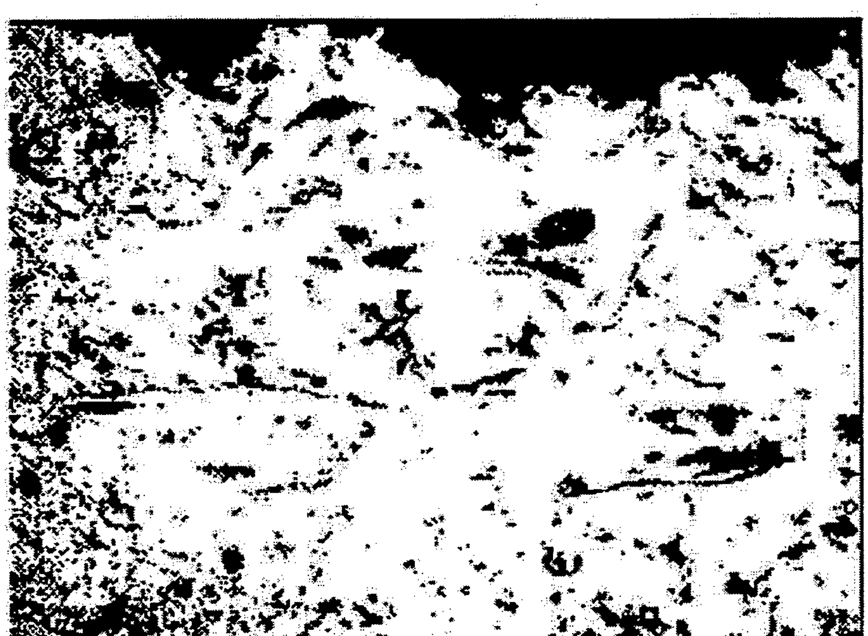

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-5BZ

Figure F5. Photomicrograph of Coating BZ5 (3/16" zinc)

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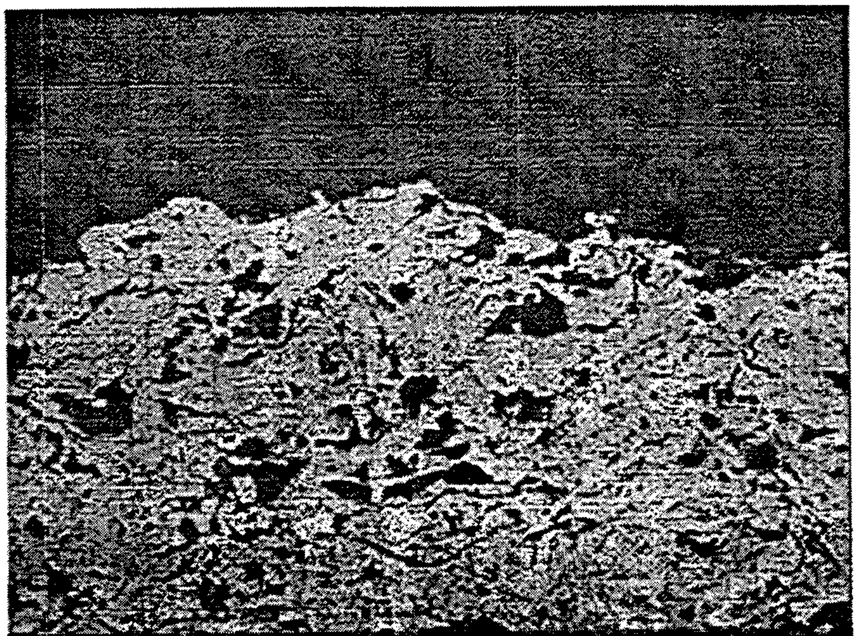

PHOTO 1 TAKEN AT 200X

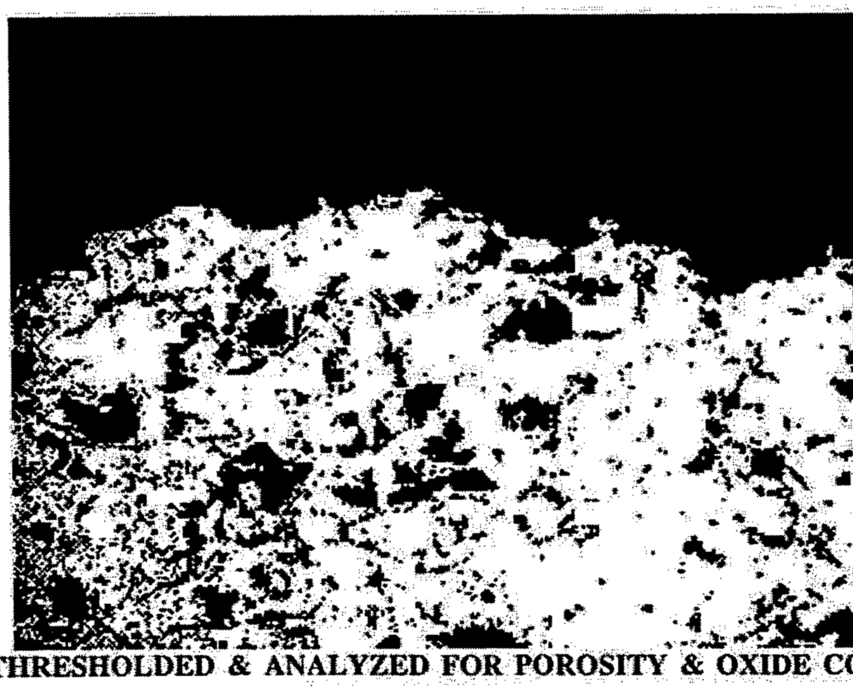

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-6BZ

Figure F6. Photomicrograph of Coating BZ6 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

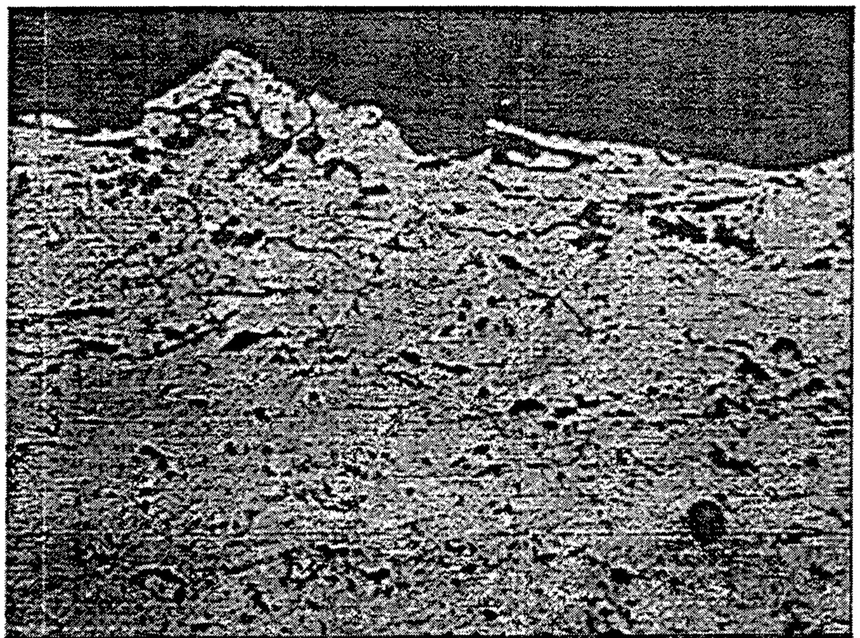

PHOTO 1 TAKEN AT 200X

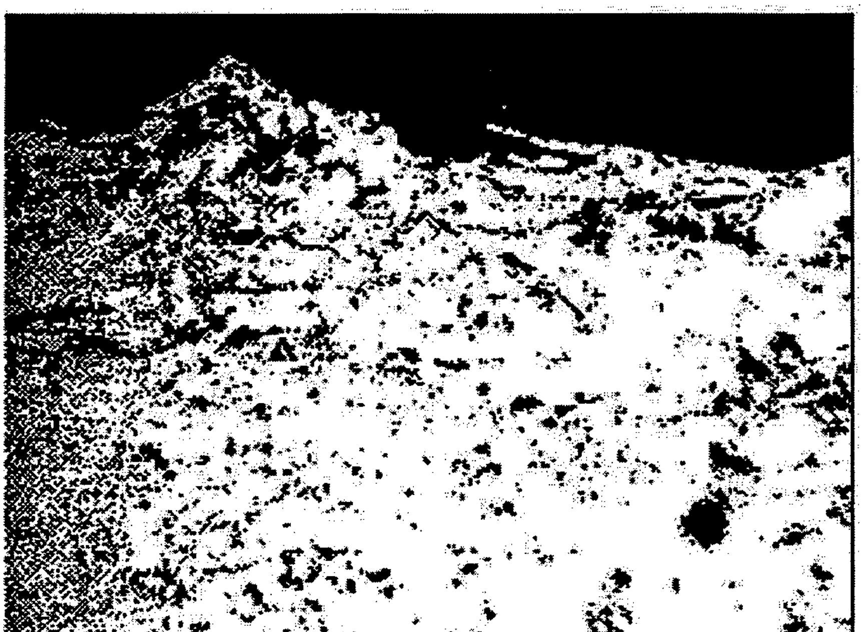

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-7BZ

Figure F7. Photomicrograph of Coating BZ7 (3/16" zinc)

PROTECH LAB CORP.

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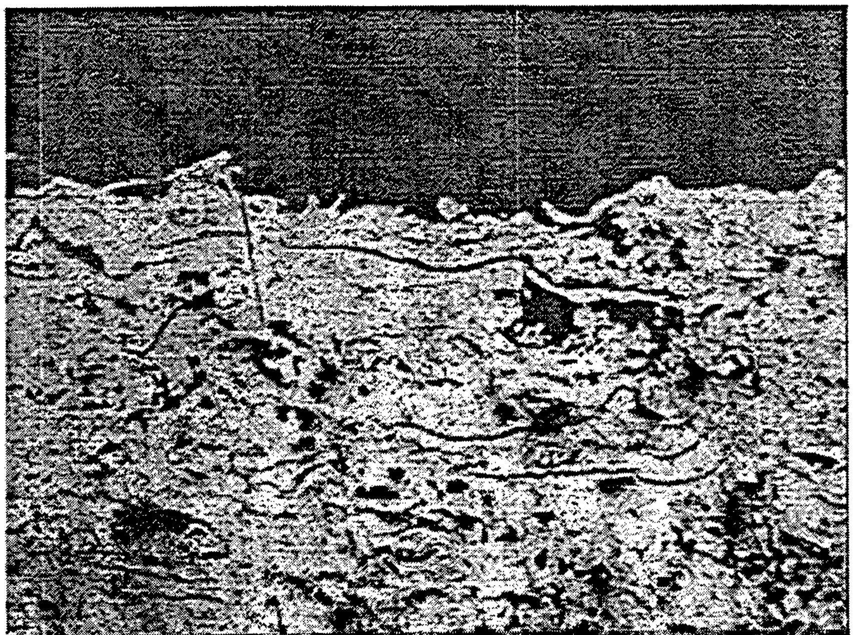

PHOTO 1 TAKEN AT 200X

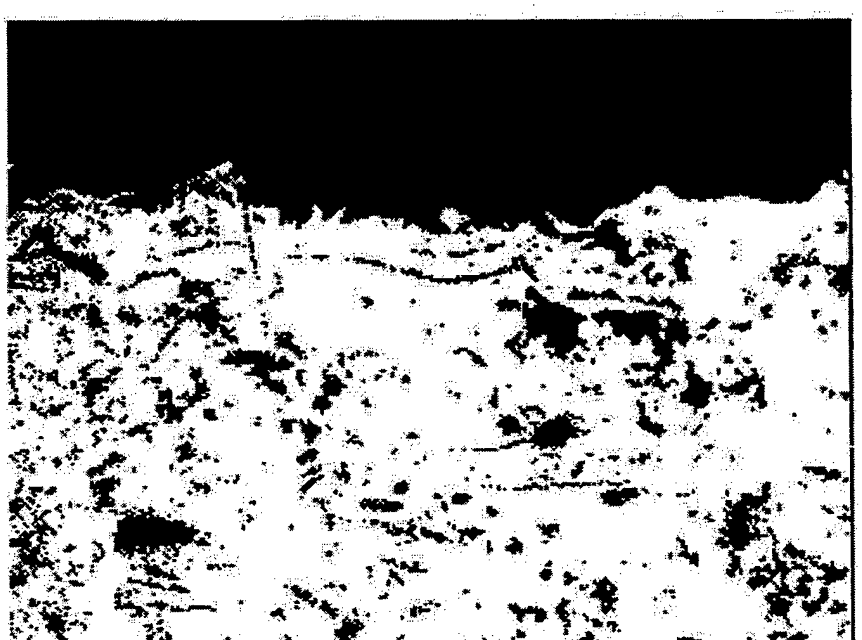

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-8BZ

Figure F8. Photomicrograph of Coating BZ8 (3/16" zinc)

PROTECH LAB CORP.
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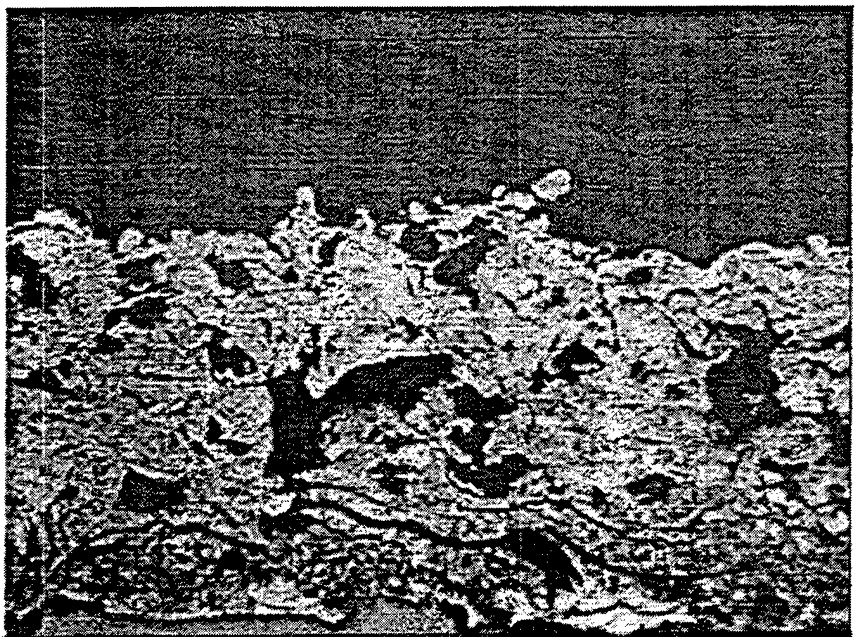

PHOTO 1 TAKEN AT 200X

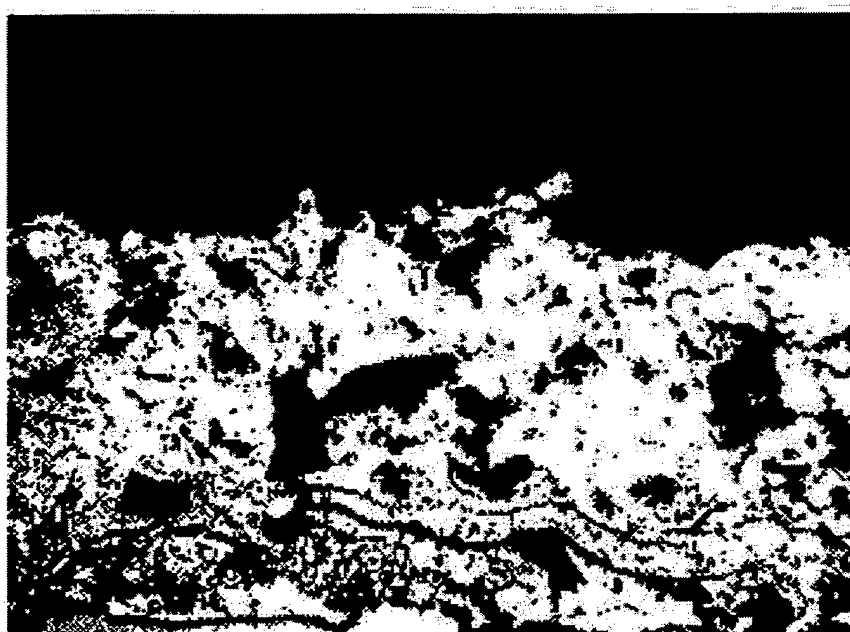

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-9BZ

Figure F9. Photomicrograph of Coating BZ9 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

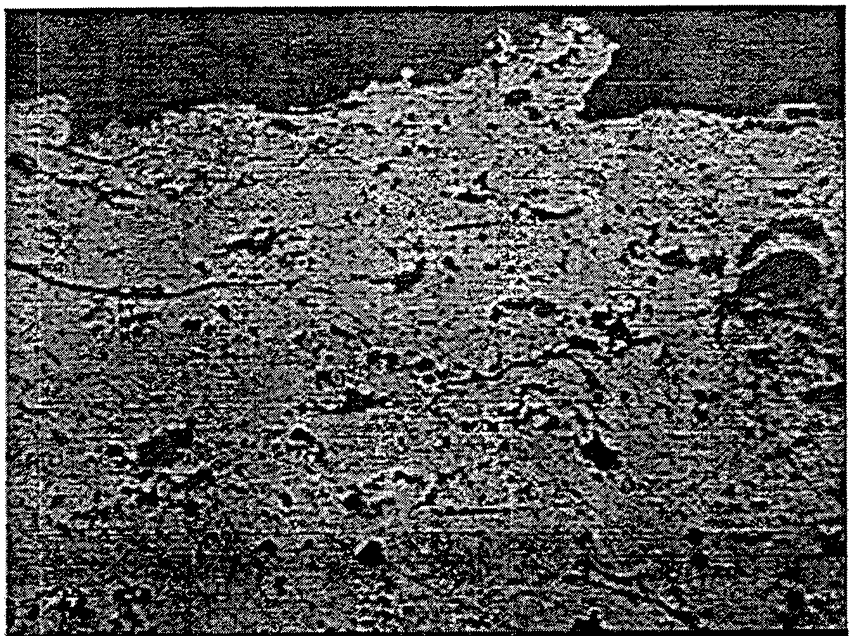

PHOTO 1 TAKEN AT 200X

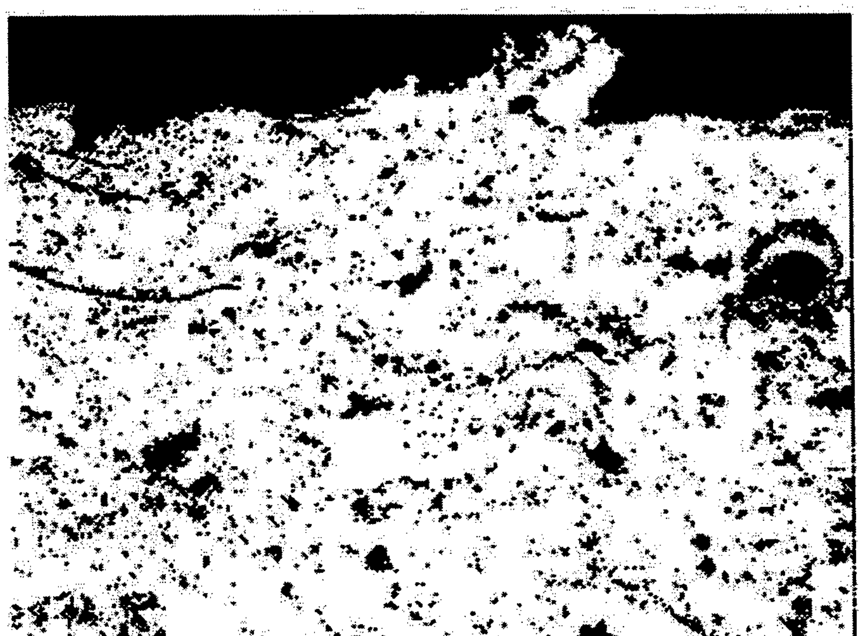

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-10BZ

Figure F10. Photomicrograph of Coating BZ10 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

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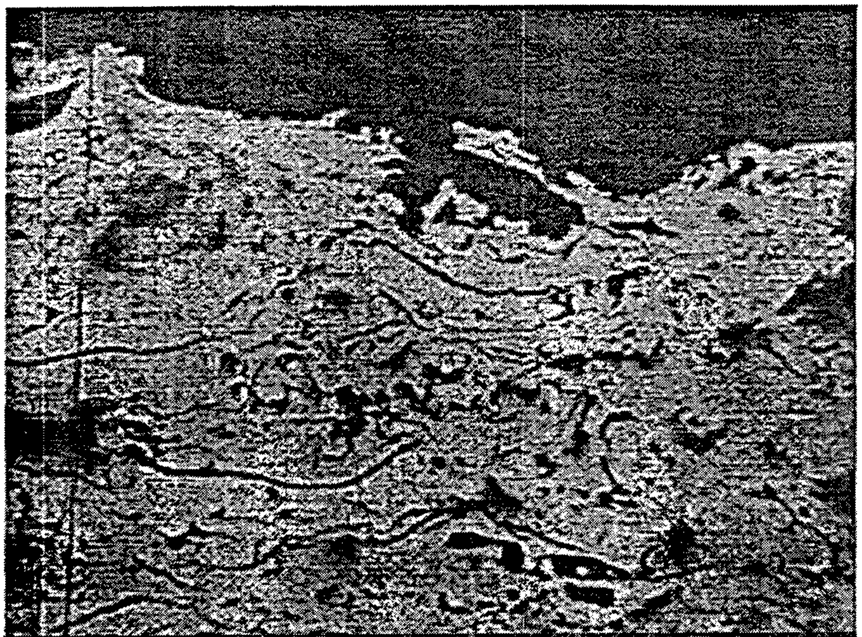

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-11BZ

Figure F11. Photomicrograph of Coating BZ11 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

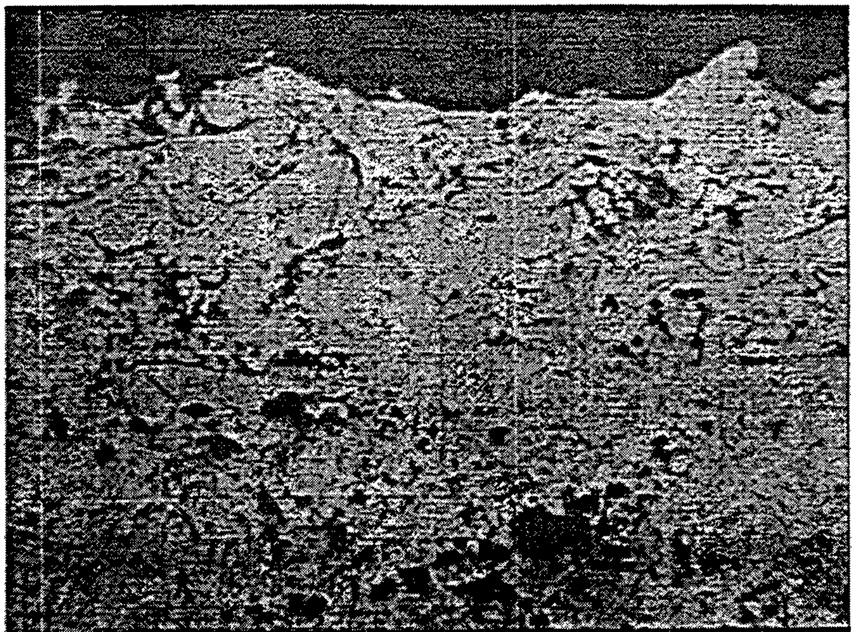

PHOTO 1 TAKEN AT 200X

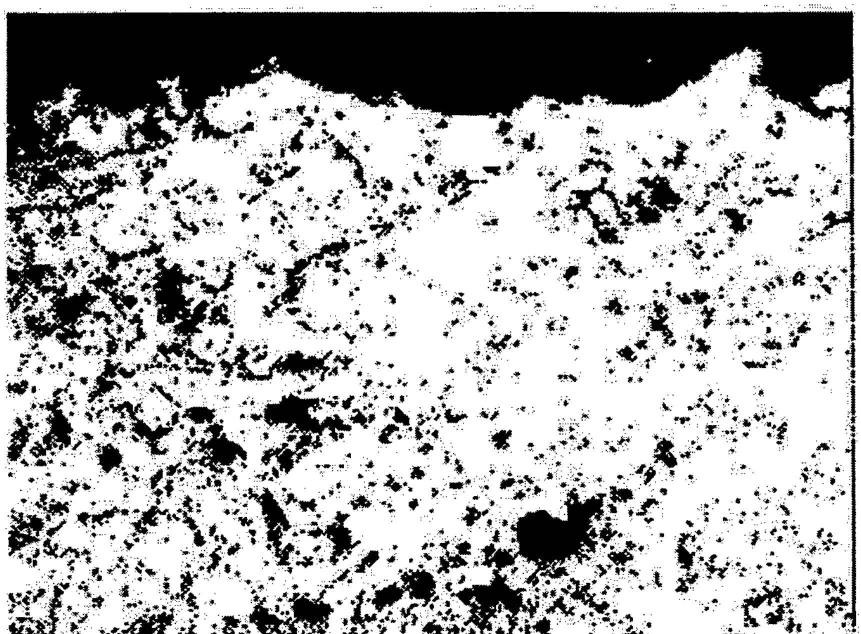

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-12BZ

Figure F12. Photomicrograph of Coating BZ12 (3/16" zinc)

PROTECH LAB CORP.
Materials Testing Services
9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

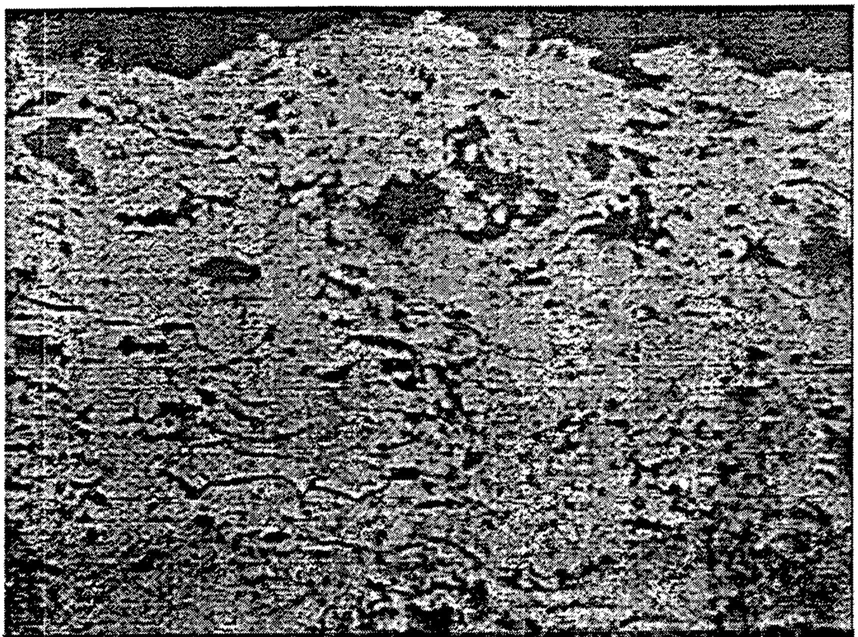

PHOTO 1 TAKEN AT 200X

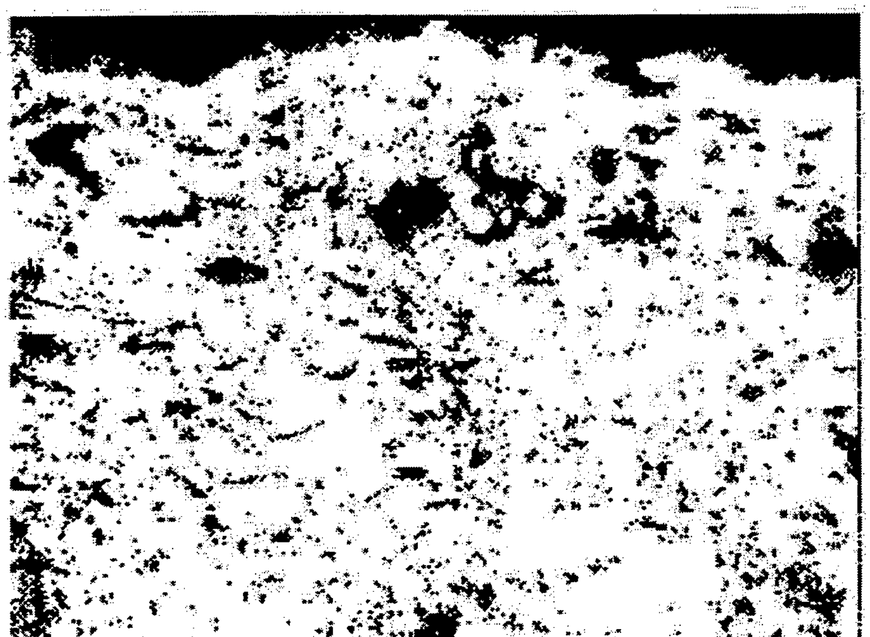

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-13BZ

Figure F13. Photomicrograph of Coating BZ13 (3/16" zinc)

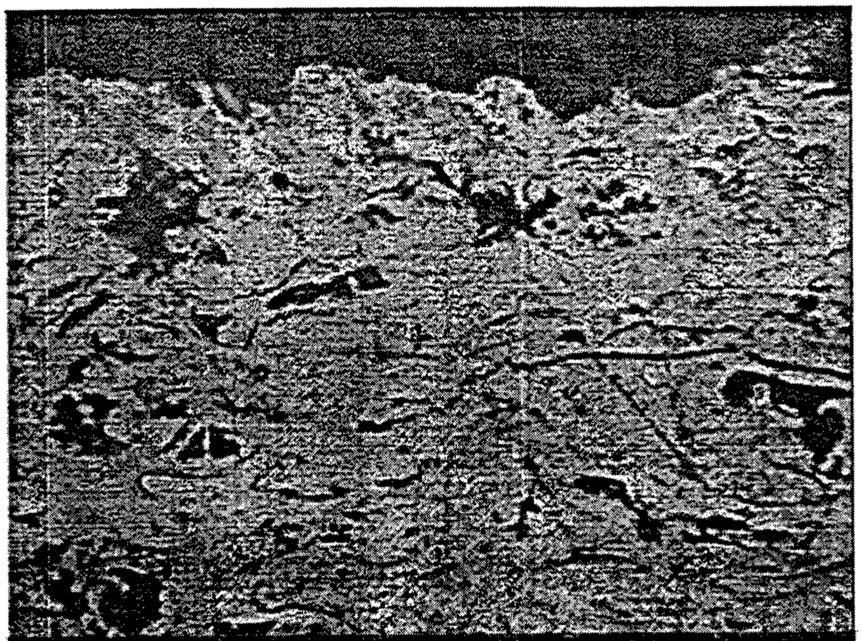

PHOTO 1 TAKEN AT 200X

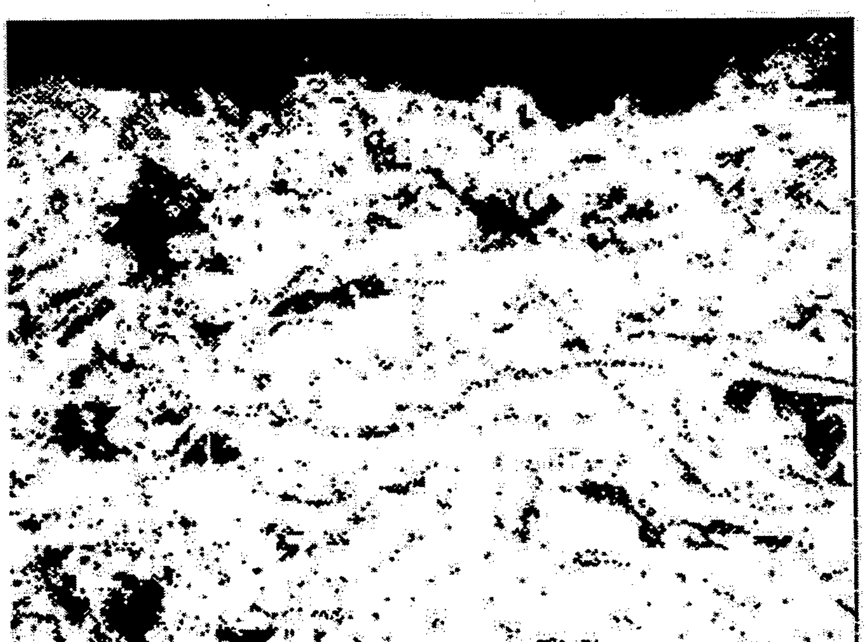

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-14BZ

Figure F14. Photomicrograph of Coating BZ14 (3/16" zinc)

PROTECH LAB CORP.
Materials Testing Services
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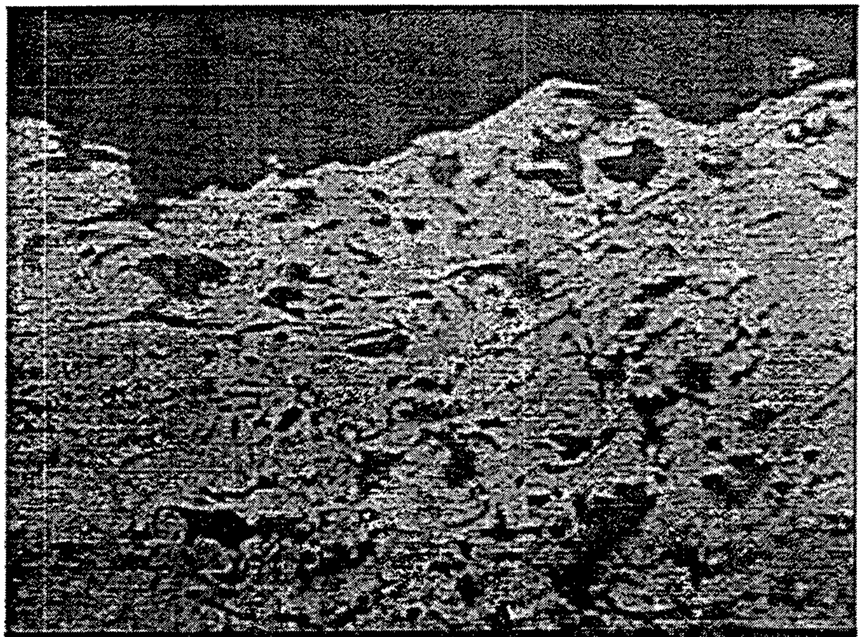

PHOTO 1 TAKEN AT 200X

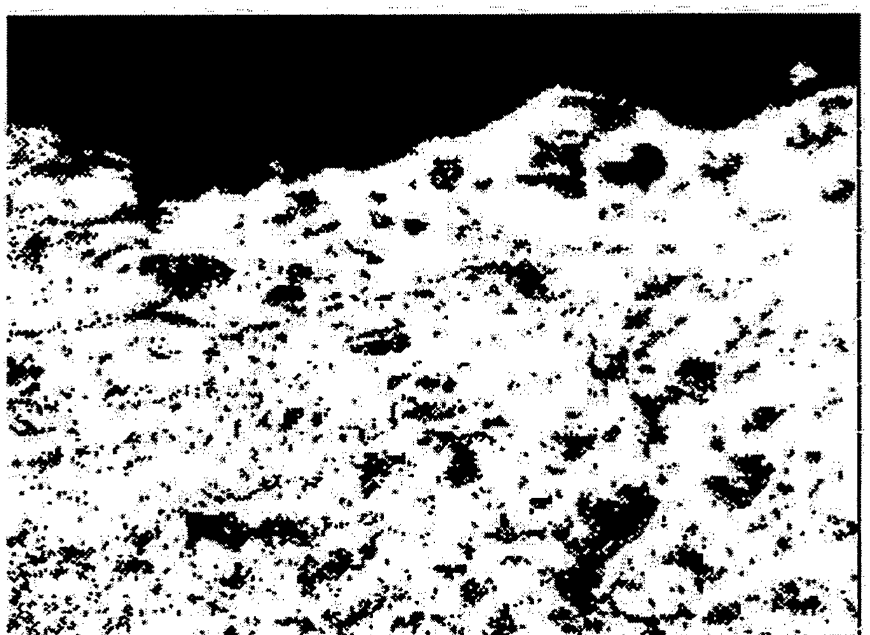

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-15BZ

Figure F15. Photomicrograph of Coating BZ15 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

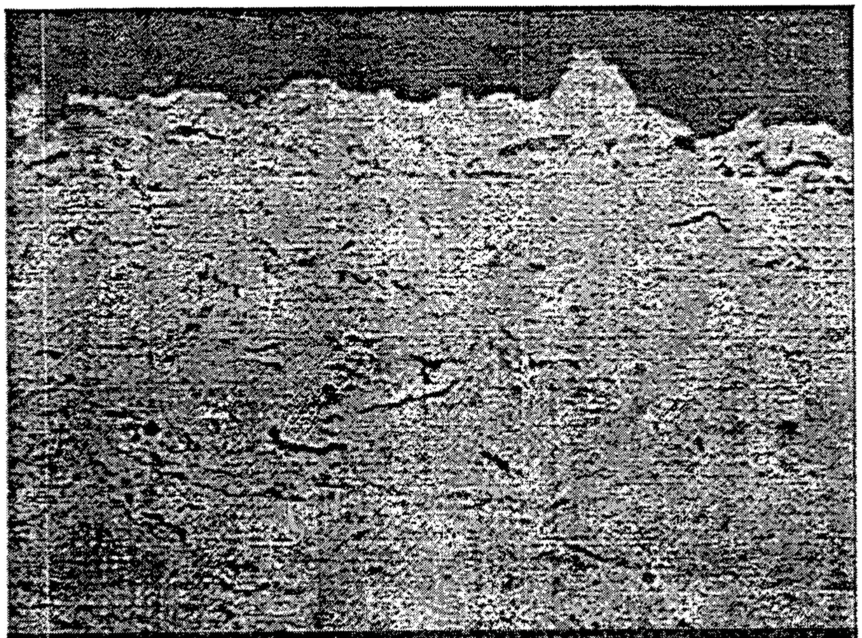

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-16BZ

Figure F16. Photomicrograph of Coating BZ16 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

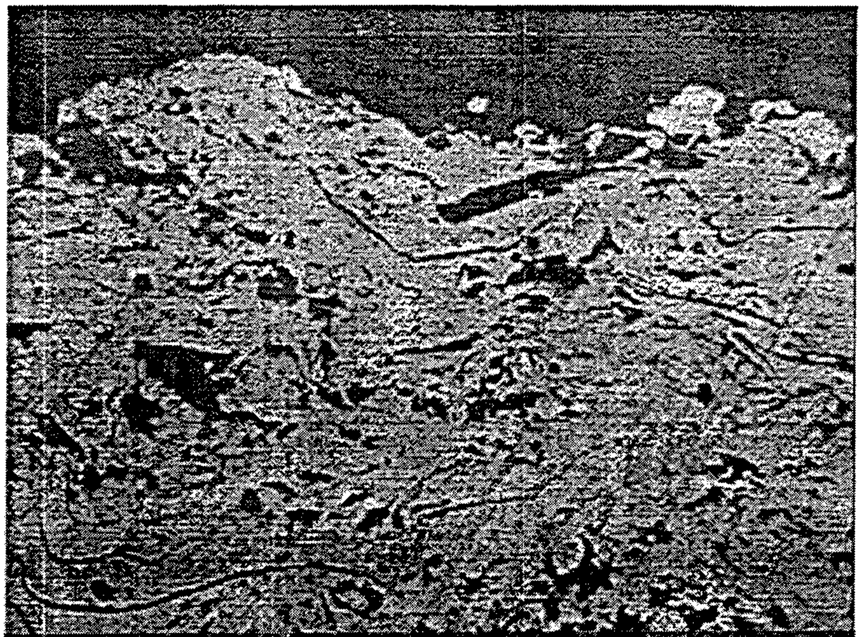

PHOTO 1 TAKEN AT 200X

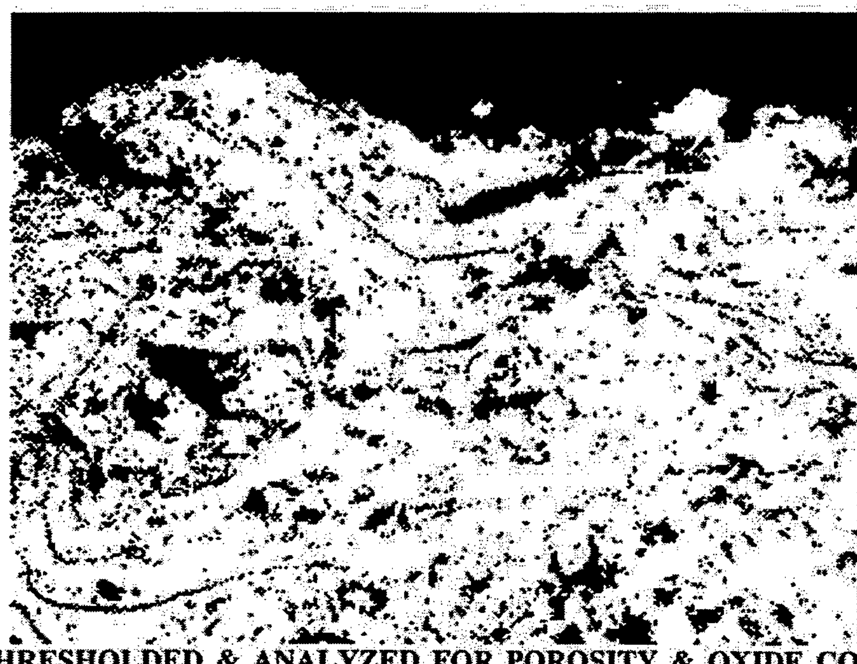

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-17BZ

Figure F17. Photomicrograph of Coating BZ17 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

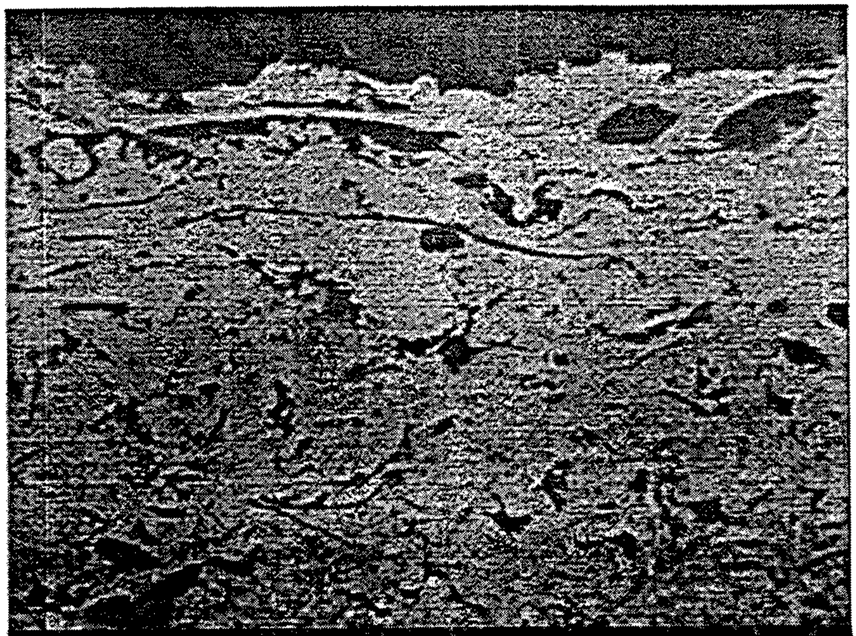

PHOTO 1 TAKEN AT 200X

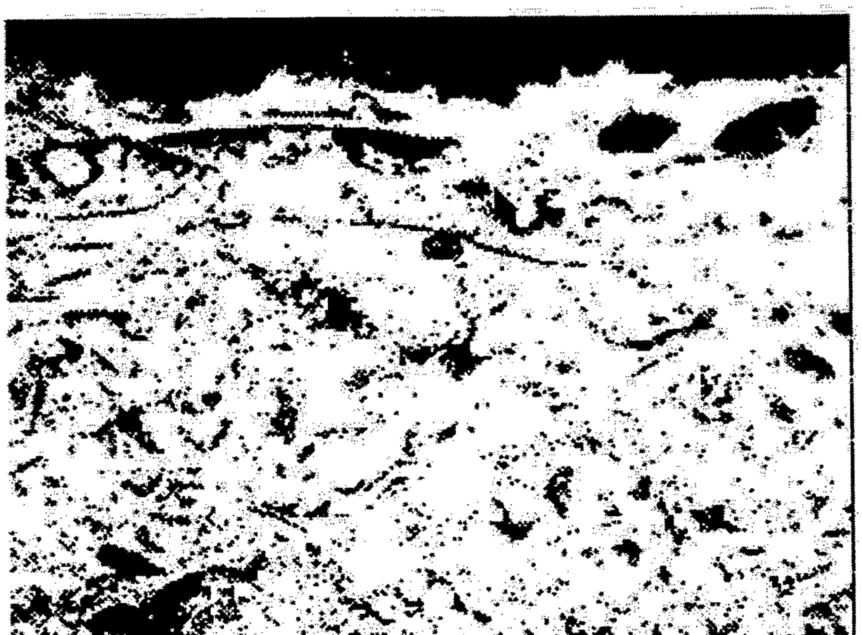

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-18BZ

Figure F18. Photomicrograph of Coating BZ18 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

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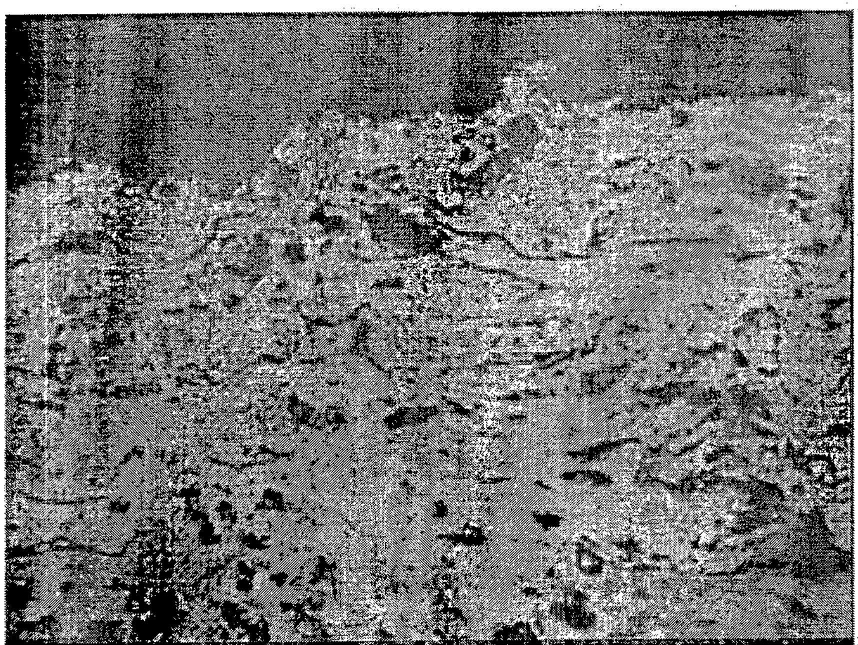

PHOTO 1 TAKEN AT 200X

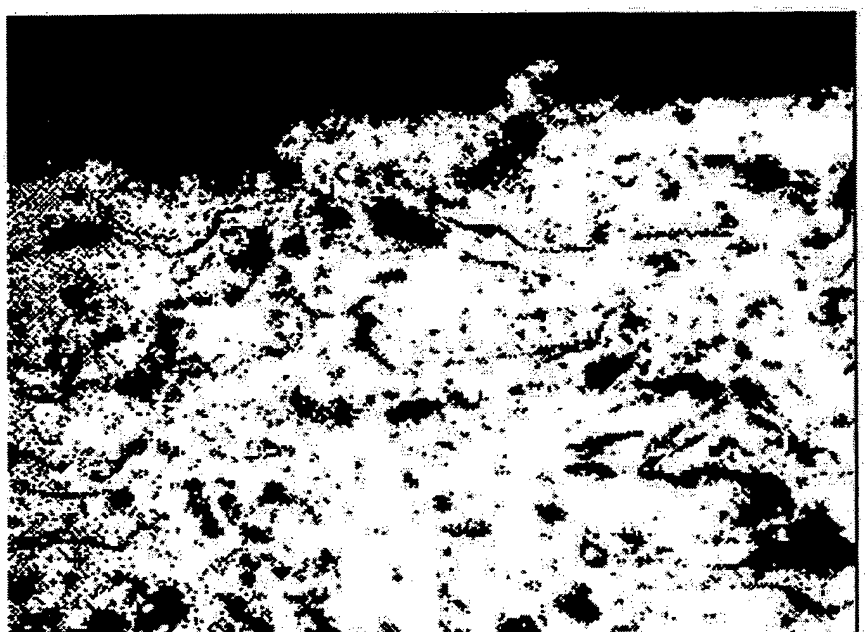

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-19BZ

Figure F19. Photomicrograph of Coating BZ19 (3/16" zinc)

PROTECH LAB CORP.

Materials Testing Services

9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

PHOTO 1 TAKEN AT 200X

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-20BZ

Figure F20. Photomicrograph of Coating BZ20 (3/16" zinc)

PROTECH LAB CORP.
Materials Testing Services
9940 Reading Road, Cincinnati, Ohio 45241, Phone: 513 563-5005 Fax 563-5004

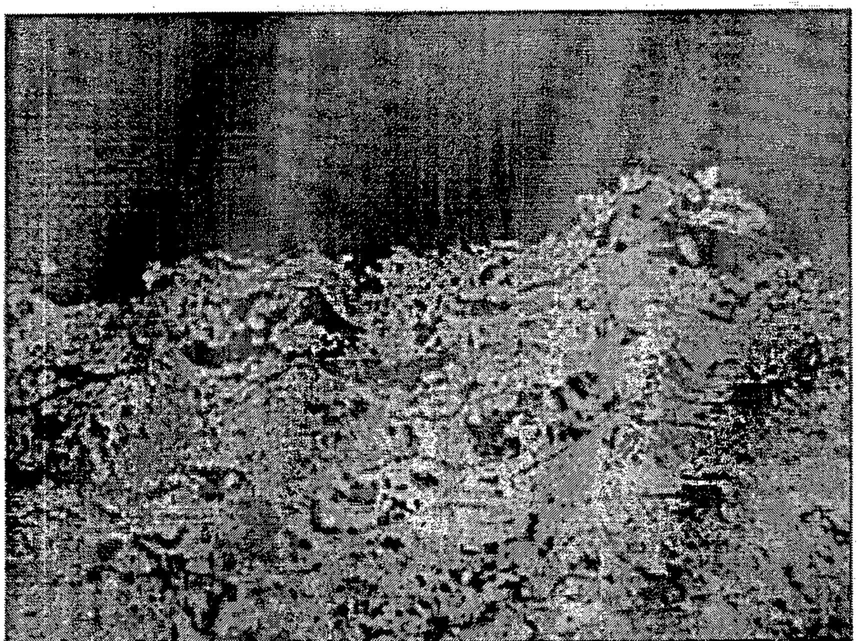

PHOTO 1 TAKEN AT 200X

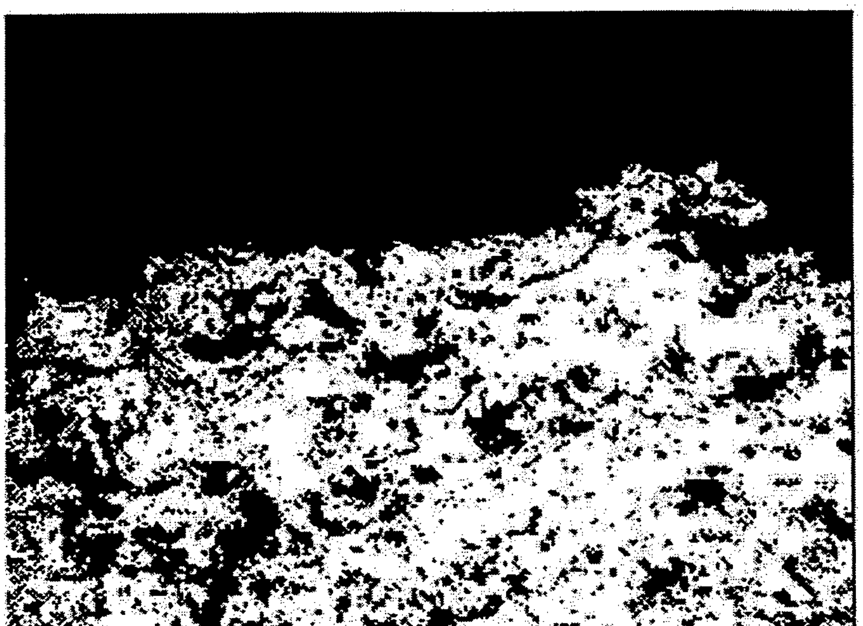

PHOTO 1 THRESHOLDED & ANALYZED FOR POROSITY & OXIDE CONTENT-21BZ

Figure F21. Photomicrograph of Coating BZ21 (3/16" zinc)

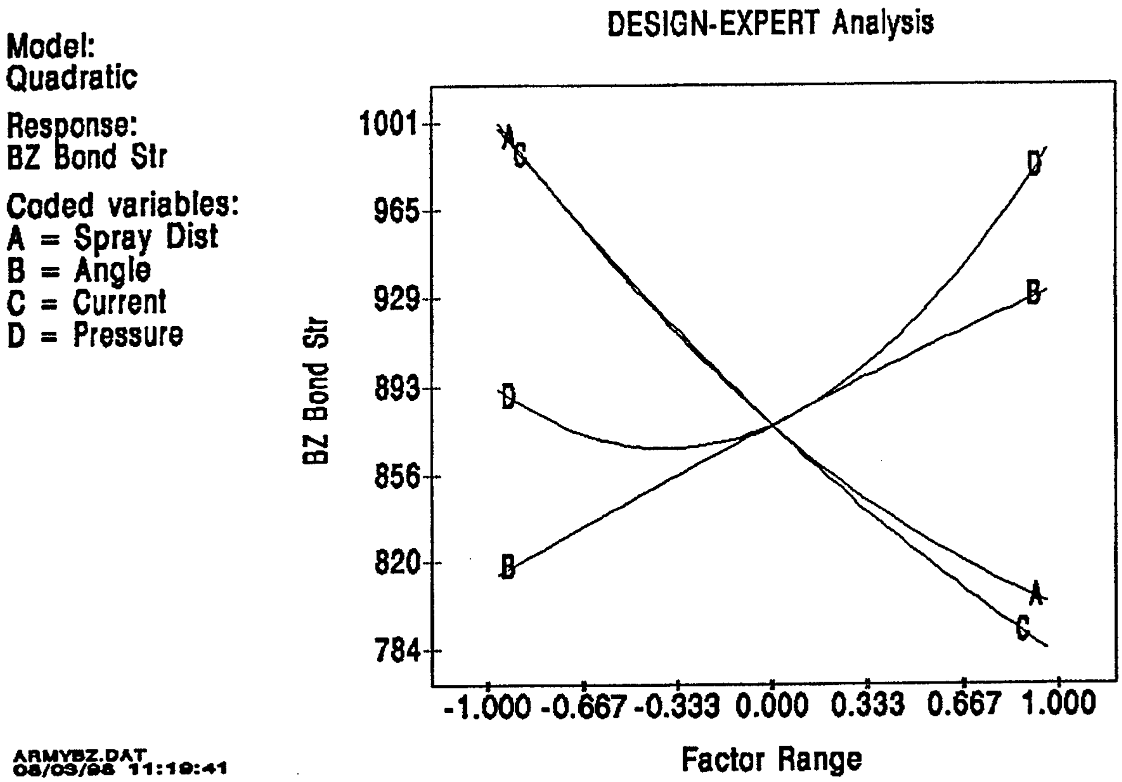

Figure F22. Bond Strength Parameter Plot for 3/16" Zn Coatings

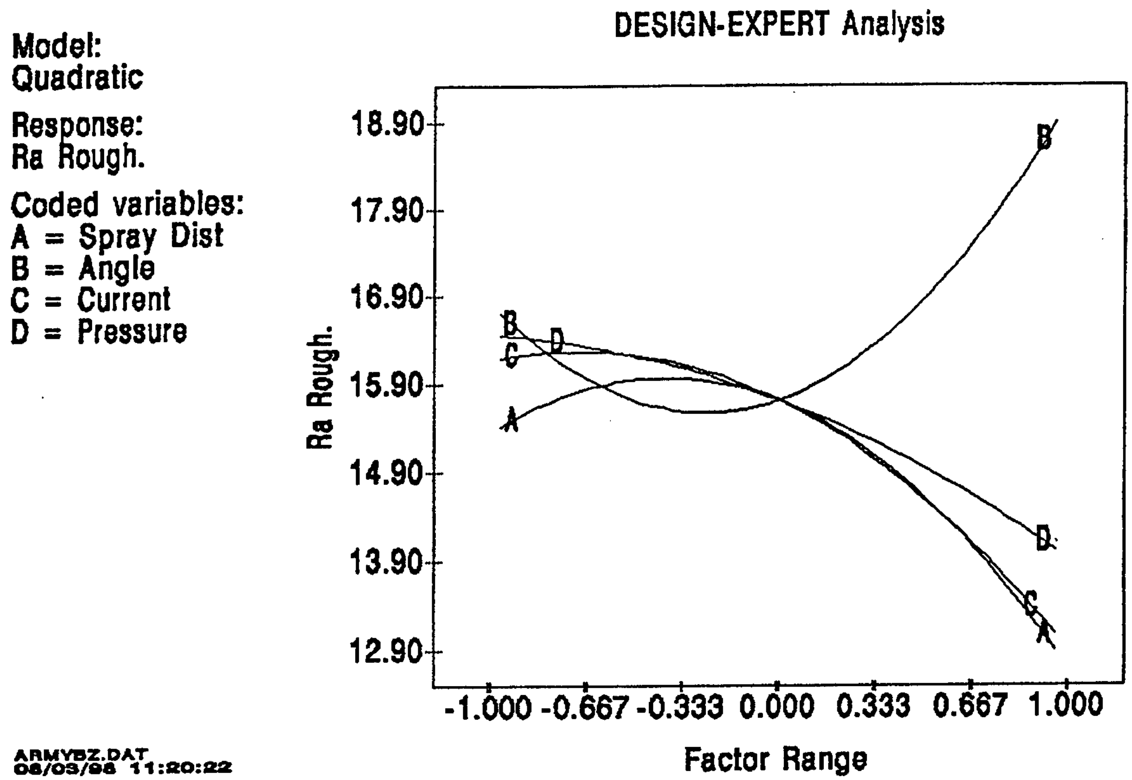

Figure F23. Roughness Parameter Plot for 3/16" Zn Coatings

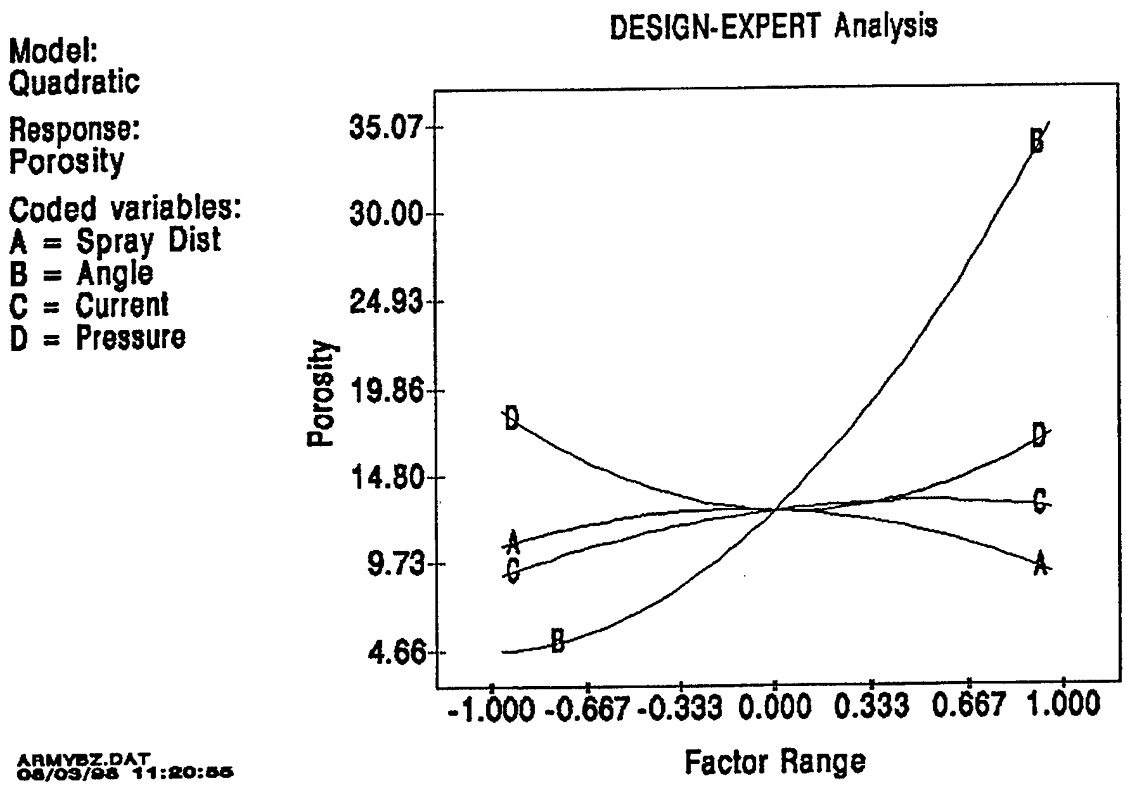

Figure F24. Porosity Parameter Plot for 3/16" Zn Coatings

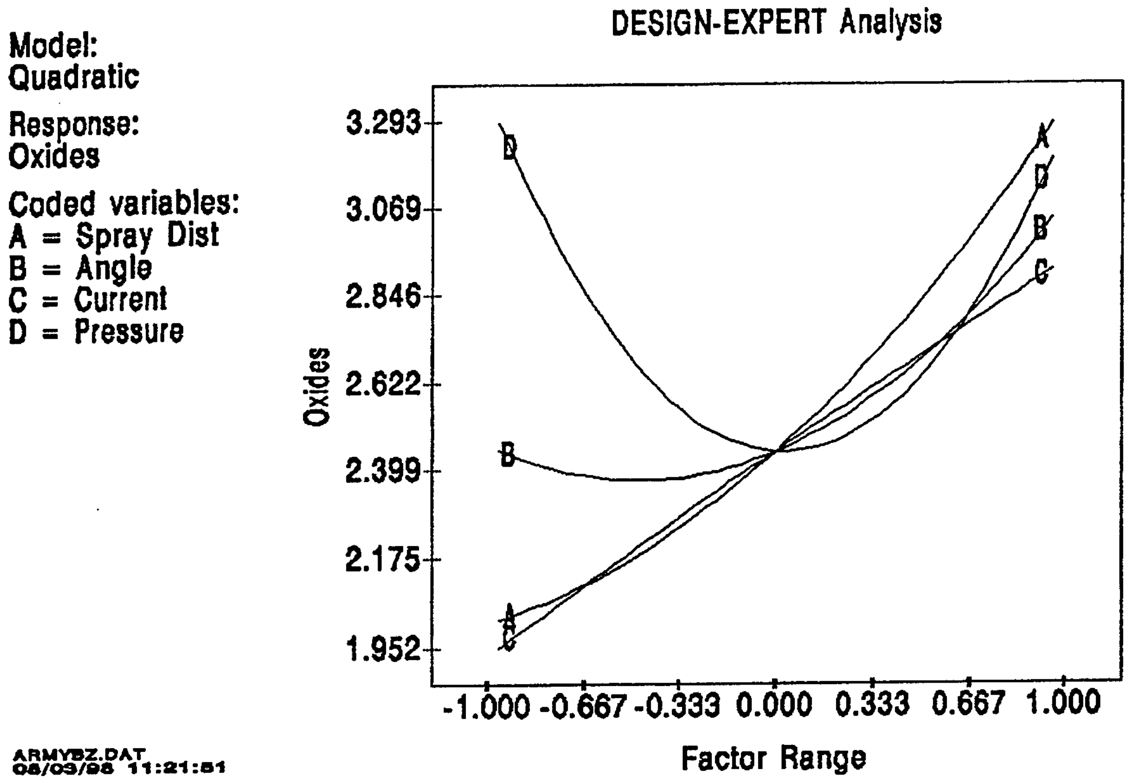

Figure F25. Oxides Parameter Plot for 3/16" Zn Coatings

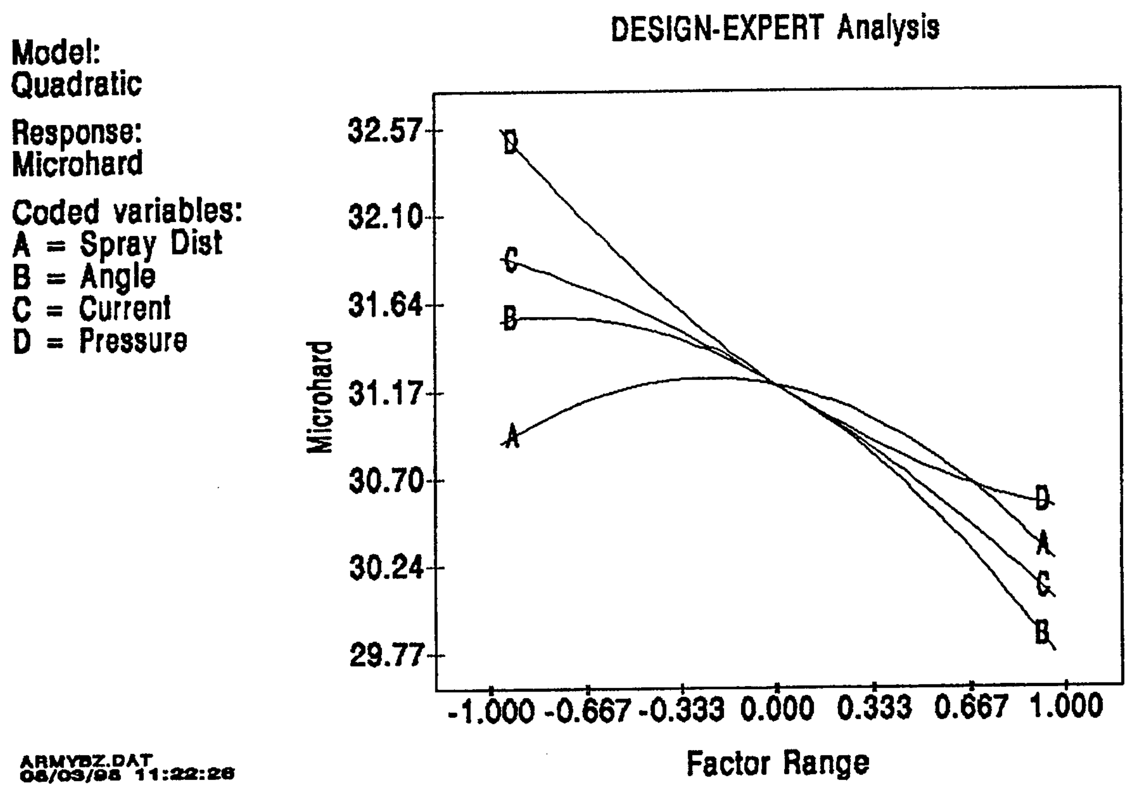

Figure F26. Hardness Parameter Plot for 3/16" Zn Coatings

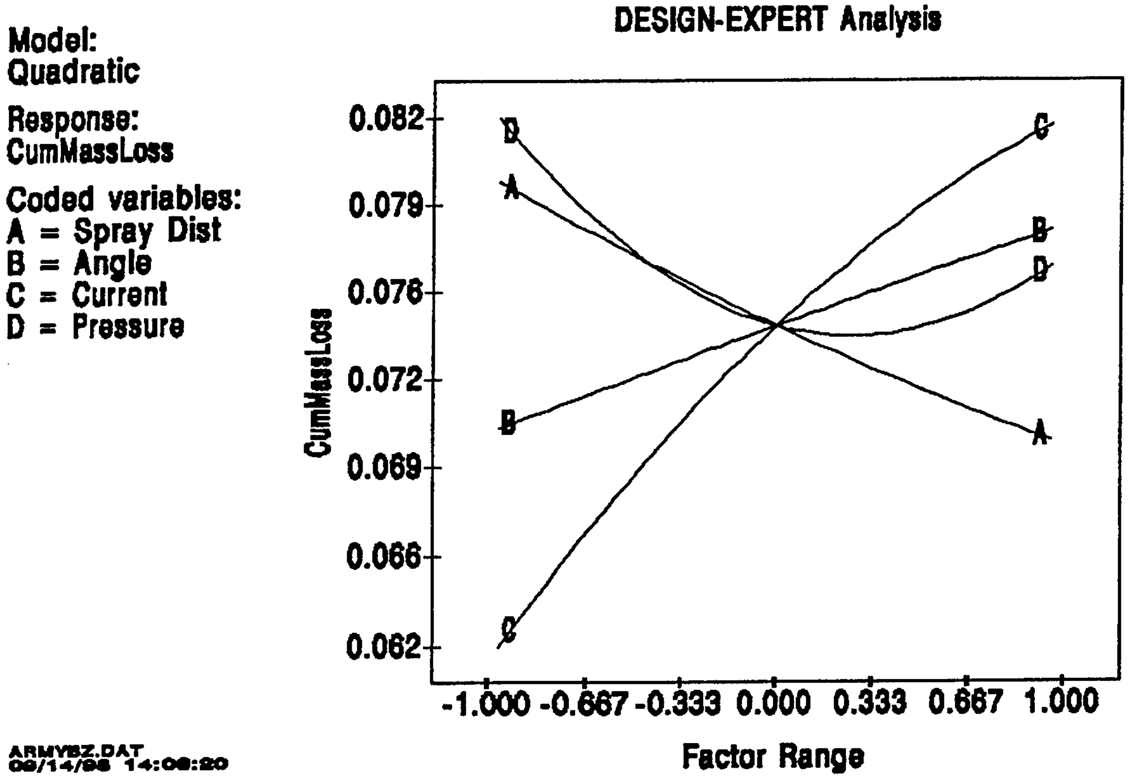

Figure F27. CML Parameter Plot for 3/16" Zn Coatings

Table F1. 3/16" Zinc Statistical Analysis of Bond Strength

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	16320531.9	1	16320531.9		
Linear	130749.5	4	32687.4	7.109	0.0017
Quadratic	59157.6	10	5915.8	2.463	0.1410
Cubic	1104.7	2	552.4	0.1661	0.8525
RESIDUAL	13305.3	4	3326.3		
TOTAL	16524849.0	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	60262.3	12	5021.9	1.510	0.3701
Quadratic	1104.7	2	552.4	0.1661	0.8525
Cubic	0.0	0			
PURE ERR	13305.3	4	3326.3		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	67.8	0.6399	0.5499	127601.1
Quadratic	15	6	49.0	0.9295	0.7649	243219.0
Cubic	17	4	57.7	0.9349	0.6744	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	189907.2	14	13564.8	5.648	0.0213
RESIDUAL	14410.0	6	2401.7		
Lack Of Fit	1104.7	2	552.4	0.1661	0.8525
Pure Error	13305.3	4	3326.3		
COR TOTAL	204317.1	20			

ROOT MSE	49.0	R-SQUARED	0.9295
DEP MEAN	881.6	ADJ R-SQUARED	0.7649
C.V.	5.56%		

Predicted Residual Sum of Squares (PRESS) = 243219.0

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	877.2	1	18.4	47.68	
A	-102.9	1	29.0	-3.545	0.0121
B	60.3	1	90.9	0.6632	0.5319
C	-112.0	1	34.7	-3.232	0.0179
D	51.0	1	34.7	1.472	0.1915
A2	27.5	1	29.1	0.9449	0.3812
B2	-4.0	1	49.7	-7.95E-02	0.9392
C2	15.6	1	28.2	0.5520	0.6009
D2	68.7	1	26.8	2.569	0.0424
AB	47.9	1	66.4	0.7212	0.4979
AC	197.3	1	69.7	2.829	0.0300

```
Final Equation in Terms of Actual Factors:
     BZ Bond Str =
                         1409.7
            +            88.398 * Spray Dist
            +            14.134 * Angle
            +            3.9579 * Current
            -            45.684 * Pressure
            +            3.0556 * Spray Dist^2
            -         7.804E-03 * Angle      ^2
            +         1.558E-03 * Current^2
            +           0.68741 * Pressure^2
            +           0.70972 * Spray Dist * Angle
            +           0.65774 * Spray Dist * Current
            -            4.7179 * Spray Dist * Pressure
            -         2.042E-02 * Angle        * Current
            -         9.289E-02 * Angle        * Pressure
            -           0.10250 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	1019.0	1023.0	-4.0	0.980	-0.582	1.112	-0.547	1
2	998.0	1007.6	-9.6	0.492	-0.275	0.005	-0.253	2
3	968.0	965.7	2.3	0.986	0.387	0.693	0.358	3
4	937.0	953.6	-16.6	0.751	-0.678	0.092	-0.644	4
5	897.0	901.0	-4.0	0.980	-0.582	1.112	-0.547	5
6	785.0	776.5	8.5	0.919	0.612	0.282	0.576	6
7	845.0	836.5	8.5	0.919	0.612	0.282	0.576	7
8	815.0	812.7	2.3	0.986	0.387	0.693	0.358	8
9	683.0	687.0	-4.0	0.980	-0.582	1.112	-0.547	9
10	1019.0	1007.6	11.4	0.492	0.326	0.007	0.300	10
11	968.0	877.2	90.8	0.141	1.999	0.044	3.158	11
12	795.0	801.8	-6.8	0.872	-0.387	0.068	-0.358	12
13	825.0	812.9	12.1	0.821	0.582	0.103	0.547	13
14	815.0	877.2	-62.2	0.141	-1.369	0.021	-1.508	14
15	734.0	740.8	-6.8	0.872	-0.387	0.068	-0.358	15
16	998.0	1004.8	-6.8	0.872	-0.387	0.068	-0.358	16
17	846.0	877.2	-31.2	0.141	-0.687	0.005	-0.653	17
18	774.0	780.8	-6.8	0.872	-0.387	0.068	-0.358	18
19	907.0	894.9	12.1	0.821	0.582	0.103	0.547	19
20	876.0	877.2	-1.2	0.141	-0.026	0.000	-0.024	20
21	1009.0	996.9	12.1	0.821	0.582	0.103	0.547	21

Table F2. 3/16" Zinc Statistical Analysis of CML

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	0.113168	1	0.113168		
Linear	0.000732	4	0.000183	1.831	0.1723
Quadratic	0.001337	10	0.000134	3.073	0.0912
Cubic	0.000184	2	0.000092	4.742	0.0880
RESIDUAL	0.000077	4	0.000019		
TOTAL	0.115498	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	0.001521	12	0.000127	6.545	0.0419
Quadratic	0.000184	2	0.000092	4.742	0.0880
Cubic	0.000000	0			
PURE ERR	0.000077	4	0.000019		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	0.01000	0.3140	0.1425	0.00369
Quadratic	15	6	0.00660	0.8879	0.6264	0.02992
Cubic	17	4	0.00440	0.9668	0.8338	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	0.002069	14	0.00015	3.396	0.0704
RESIDUAL	0.000261	6	0.00004		
Lack Of Fit	0.000184	2	0.00009	4.742	0.0880
Pure Error	0.000077	4	0.00002		
COR TOTAL	0.002330	20			

ROOT MSE	0.00660	R-SQUARED	0.8879
DEP MEAN	0.07341	ADJ R-SQUARED	0.6264
C.V.	8.99%		

Predicted Residual Sum of Squares (PRESS) = 0.029917

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	0.07435	1	0.00248	30.02	
A	-0.00518	1	0.00391	-1.325	0.2333
B	0.00394	1	0.01224	0.3220	0.7584
C	0.01030	1	0.00466	2.208	0.0693
D	-0.00295	1	0.00466	-0.6324	0.5505
A2	0.00061	1	0.00392	0.1553	0.8817
B2	-0.00015	1	0.00669	-2.19E-02	0.9832
C2	-0.00237	1	0.00380	-0.6239	0.5557

Table F2. 3/16" Zinc Statistical Analysis of CML

AB	-0.01895	1	0.00894	-2.120	0.0783
AC	-0.01834	1	0.00939	-1.953	0.0986
AD	0.00983	1	0.01015	0.9684	0.3702
BC	0.00684	1	0.00438	1.562	0.1694
BD	0.00135	1	0.00680	0.1991	0.8488
CD	0.01178	1	0.01005	1.172	0.2855

Final Equation in Terms of Actual Factors:

CumMassLoss =

```
                1.03503
    +       1.096E-02 * Spray Dist
    +       1.089E-03 * Angle
    -       6.331E-04 * Current
    -       1.903E-02 * Pressure
    +       6.761E-05 * Spray Dist^2
    -       2.895E-07 * Angle      ^2
    -       2.370E-07 * Current^2
    +       5.561E-05 * Pressure^2
    -       2.808E-04 * Spray Dist * Angle
    -       6.112E-05 * Spray Dist * Current
    +       3.276E-04 * Spray Dist * Pressure
    +       3.041E-06 * Angle        * Current
    +       6.015E-06 * Angle        * Pressure
    +       1.178E-05 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	0.06560	0.06441	0.00119	0.980	1.277	5.360	1.367	1
2	0.08120	0.08014	0.00106	0.492	0.225	0.003	0.206	2
3	0.04940	0.04821	0.00119	0.986	1.520	10.691	1.769	3
4	0.07270	0.07152	0.00118	0.751	0.357	0.026	0.330	4
5	0.08020	0.07901	0.00119	0.980	1.277	5.360	1.367	5
6	0.06810	0.06690	0.00120	0.919	0.639	0.308	0.604	6
7	0.06860	0.06740	0.00120	0.919	0.639	0.308	0.604	7
8	0.07730	0.07611	0.00119	0.986	1.520	10.691	1.769	8
9	0.10180	0.10061	0.00119	0.980	1.277	5.360	1.367	9
10	0.07670	0.08014	-0.00344	0.492	-0.732	0.035	-0.700	10
11	0.07890	0.07435	0.00455	0.141	0.743	0.006	0.712	11
12	0.06620	0.06978	-0.00358	0.872	-1.520	1.051	-1.769	12
13	0.06670	0.07027	-0.00357	0.821	-1.277	0.499	-1.367	13
14	0.07290	0.07435	-0.00145	0.141	-0.238	0.001	-0.218	14
15	0.06230	0.06588	-0.00358	0.872	-1.520	1.051	-1.769	15
16	0.05810	0.06168	-0.00358	0.872	-1.520	1.051	-1.769	16
17	0.08450	0.07435	0.01015	0.141	1.659	0.030	2.059	17
18	0.07870	0.08228	-0.00358	0.872	-1.520	1.051	-1.769	18
19	0.07930	0.08287	-0.00357	0.821	-1.277	0.499	-1.367	19
20	0.07900	0.07435	0.00465	0.141	0.760	0.006	0.730	20
21	0.07340	0.07697	-0.00357	0.821	-1.277	0.499	-1.367	21

Table F3. 3/16" Zinc Statistical Analysis of Microhardness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	20137.62	1	20137.62		
Linear	10.04	4	2.51	0.5215	0.7214
Quadratic	34.94	10	3.49	0.4986	0.8420
Cubic	4.13	2	2.06	0.2178	0.8133
RESIDUAL	37.92	4	9.48		
TOTAL	20224.65	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	39.07	12	3.26	0.3434	0.9325
Quadratic	4.13	2	2.06	0.2178	0.8133
Cubic	0.00	0			
PURE ERR	37.92	4	9.48		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	2.194	0.1153	-0.1058	149.274
Quadratic	15	6	2.647	0.5168	-0.6106	829.636
Cubic	17	4	3.079	0.5643	-1.1786	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	44.98	14	3.213	0.4584	0.8925
RESIDUAL	42.05	6	7.008		
Lack Of Fit	4.13	2	2.064	0.2178	0.8133
Pure Error	37.92	4	9.480		
COR TOTAL	87.03	20			

ROOT MSE	2.647	R-SQUARED	0.5168
DEP MEAN	30.967	ADJ R-SQUARED	-0.6106
C.V.	8.55%		

Predicted Residual Sum of Squares (PRESS) = 829.64

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	31.204	1	0.994	31.39	
A	-0.328	1	1.568	-0.2092	0.8412
B	-0.927	1	4.913	-0.1887	0.8565
C	-0.950	1	1.872	-0.5075	0.6299
D	-1.050	1	1.872	-0.5609	0.5952
A2	-0.675	1	1.572	-0.4292	0.6828
B2	-0.589	1	2.684	-0.2196	0.8335
C2	-0.253	1	1.525	-0.1658	0.8737
D2	0.388	1	1.445	0.2684	0.7974
AB	2.080	1	3.588	0.5796	0.5833

CD	-2.081	1	4.034	-0.5158	0.6244

Final Equation in Terms of Actual Factors:

Microhard =

```
                 -33.364
        +         8.0852 * Spray Dist
        -        0.45515 * Angle
        +        0.24052 * Current
        +        0.31666 * Pressure
        -      7.496E-02 * Spray Dist^2
        -      1.164E-03 * Angle     ^2
        -      2.528E-05 * Current^2
        +      3.879E-03 * Pressure^2
        +      3.081E-02 * Spray Dist * Angle
        -      4.284E-03 * Spray Dist * Current
        -      8.119E-02 * Spray Dist * Pressure
        +      1.589E-04 * Angle      * Current
        +      2.905E-03 * Angle      * Pressure
        -      2.081E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	30.900	30.619	0.281	0.980	0.751	1.854	0.721	1
2	34.600	30.857	3.743	0.492	1.984	0.254	3.087	2
3	32.300	32.266	0.034	0.986	0.107	0.053	0.097	3
4	31.000	30.226	0.774	0.751	0.586	0.069	0.551	4
5	33.800	33.519	0.281	0.980	0.751	1.854	0.721	5
6	31.900	32.113	-0.213	0.919	-0.283	0.060	-0.260	6
7	25.400	25.613	-0.213	0.919	-0.283	0.060	-0.260	7
8	31.200	31.166	0.034	0.986	0.107	0.053	0.097	8
9	31.000	30.719	0.281	0.980	0.751	1.854	0.721	9
10	26.800	30.857	-4.057	0.492	-2.150	0.299	-4.098	10
11	32.900	31.204	1.696	0.141	0.691	0.005	0.658	11
12	30.100	30.201	-0.101	0.872	-0.107	0.005	-0.097	12
13	30.700	31.542	-0.842	0.821	-0.751	0.173	-0.721	13
14	31.000	31.204	-0.204	0.141	-0.083	0.000	-0.076	14
15	30.600	30.701	-0.101	0.872	-0.107	0.005	-0.097	15
16	31.800	31.901	-0.101	0.872	-0.107	0.005	-0.097	16
17	29.800	31.204	-1.404	0.141	-0.572	0.004	-0.537	17
18	29.900	30.001	-0.101	0.872	-0.107	0.005	-0.097	18
19	31.800	32.642	-0.842	0.821	-0.751	0.173	-0.721	19
20	33.100	31.204	1.896	0.141	0.773	0.007	0.744	20
21	29.700	30.542	-0.842	0.821	-0.751	0.173	-0.721	21

Table F4. 3/16" Zinc Statistical Analysis of Oxides

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	187.80	1	187.80		
Linear	11.32	4	2.83	2.495	0.0843
Quadratic	6.38	10	0.64	0.3252	0.9434
Cubic	3.45	2	1.72	0.8297	0.4995
RESIDUAL	8.31	4	2.08		
TOTAL	217.26	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	9.83	12	0.82	0.3939	0.9053
Quadratic	3.45	2	1.72	0.8297	0.4995
Cubic	0.00	0			
PURE ERR	8.31	4	2.08		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	1.065	0.3841	0.2302	33.630
Quadratic	15	6	1.400	0.6006	-0.3312	573.068
Cubic	17	4	1.442	0.7177	-0.4113	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	17.69	14	1.264	0.6446	0.7670
RESIDUAL	11.76	6	1.961		
Lack Of Fit	3.45	2	1.725	0.8297	0.4995
Pure Error	8.31	4	2.079		
COR TOTAL	29.46	20			

ROOT MSE	1.400	R-SQUARED	0.6006
DEP MEAN	2.990	ADJ R-SQUARED	-0.3312
C.V.	46.82%		

Predicted Residual Sum of Squares (PRESS) = 573.07

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	2.446	1	0.526	4.652	
A	0.657	1	0.829	0.7926	0.4582
B	0.308	1	2.598	0.1185	0.9095
C	0.500	1	0.990	0.5050	0.6316
D	-0.050	1	0.990	-5.05E-02	0.9614
A2	0.227	1	0.832	0.2732	0.7938
B2	0.325	1	1.419	0.2290	0.8264
C2	-0.015	1	0.806	-1.91E-02	0.9854
D2	0.867	1	0.765	1.134	0.3000

BD	0.156	1	1.443	0.1082	0.9174
CD	0.435	1	2.134	0.2040	0.8451

Final Equation in Terms of Actual Factors:

```
        Oxides =
                         90.218
        +                2.8569 * Spray Dist
        -               0.26292 * Angle
        -             5.111E-02 * Current
        -                1.6416 * Pressure
        +             2.524E-02 * Spray Dist^2
        +             6.422E-04 * Angle     ^2
        -             1.539E-06 * Current^2
        +             8.672E-03 * Pressure^2
        +             4.252E-03 * Spray Dist * Angle
        -             5.037E-06 * Spray Dist * Current
        -             3.473E-02 * Spray Dist * Pressure
        +             1.524E-04 * Angle      * Current
        +             6.940E-04 * Angle      * Pressure
        +             4.352E-04 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	2.800	2.612	0.188	0.980	0.950	2.966	0.941	1
2	0.500	2.016	-1.516	0.492	-1.519	0.149	-1.767	2
3	5.200	5.057	0.143	0.986	0.860	3.422	0.838	3
4	3.400	3.124	0.276	0.751	0.395	0.031	0.365	4
5	3.600	3.412	0.188	0.980	0.950	2.966	0.941	5
6	3.400	3.301	0.099	0.919	0.249	0.047	0.228	6
7	3.300	3.201	0.099	0.919	0.249	0.047	0.228	7
8	2.300	2.157	0.143	0.986	0.860	3.422	0.838	8
9	5.900	5.712	0.188	0.980	0.950	2.966	0.941	9
10	3.200	2.016	1.184	0.492	1.187	0.091	1.239	10
11	3.800	2.446	1.354	0.141	1.043	0.012	1.053	11
12	2.900	3.330	-0.430	0.872	-0.860	0.336	-0.838	12
13	1.900	2.463	-0.563	0.821	-0.950	0.276	-0.941	13
14	1.800	2.446	-0.646	0.141	-0.498	0.003	-0.464	14
15	2.700	3.130	-0.430	0.872	-0.860	0.336	-0.838	15
16	1.500	1.930	-0.430	0.872	-0.860	0.336	-0.838	16
17	2.200	2.446	-0.246	0.141	-0.189	0.000	-0.173	17
18	2.500	2.930	-0.430	0.872	-0.860	0.336	-0.838	18
19	2.800	3.363	-0.563	0.821	-0.950	0.276	-0.941	19
20	4.400	2.446	1.954	0.141	1.506	0.025	1.743	20
21	2.700	3.263	-0.563	0.821	-0.950	0.276	-0.941	21

Table F5. 3/16" Zinc Statistical Analysis of Porosity

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	2647.7	1	2647.7		
Linear	22.5	4	5.6	0.3447	0.8438
Quadratic	223.5	10	22.4	3.569	0.0665
Cubic	13.7	2	6.9	1.152	0.4026
RESIDUAL	23.8	4	6.0		
TOTAL	2931.3	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	237.3	12	19.8	3.317	0.1286
Quadratic	13.7	2	6.9	1.152	0.4026
Cubic	0.0	0			
PURE ERR	23.8	4	6.0		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	4.04	0.0793	-0.1508	430.04
Quadratic	15	6	2.50	0.8675	0.5583	2881.64
Cubic	17	4	2.44	0.9159	0.5796	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	246.0	14	17.57	2.806	0.1056
RESIDUAL	37.6	6	6.26		
Lack Of Fit	13.7	2	6.87	1.152	0.4026
Pure Error	23.8	4	5.96		
COR TOTAL	283.6	20			

ROOT MSE	2.50	R-SQUARED	0.8675
DEP MEAN	11.23	ADJ R-SQUARED	0.5583
C.V.	22.29%		

Predicted Residual Sum of Squares (PRESS) = 2881.6

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	12.79	1	0.94	13.61	
A	-0.83	1	1.48	-0.5602	0.5956
B	15.84	1	4.64	3.410	0.0143
C	2.00	1	1.77	1.130	0.3016
D	-0.70	1	1.77	-0.3955	0.7061
A2	-3.12	1	1.49	-2.101	0.0803
B2	7.68	1	2.54	3.027	0.0232
C2	-1.95	1	1.44	-1.355	0.2241
D2	5.54	1	1.37	4.057	0.0067
AB	-6.59	1	3.39	-1.944	0.0999

CD	11.05	1	3.81	2.898	0.0274

Final Equation in Terms of Actual Factors:

Porosity =

```
              1022.78
  -            11.171 * Spray Dist
  -         8.783E-02 * Angle
  -           0.88977 * Current
  -            16.610 * Pressure
  -           0.34698 * Spray Dist^2
  +         1.517E-02 * Angle      ^2
  -         1.953E-04 * Current^2
  +         5.543E-02 * Pressure^2
  -         9.768E-02 * Spray Dist * Angle
  -         8.246E-03 * Spray Dist * Current
  +           0.28817 * Spray Dist * Pressure
  +         1.723E-04 * Angle        * Current
  -         1.120E-02 * Angle        * Pressure
  +         1.105E-02 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	12.90	13.12	-0.22	0.980	-0.634	1.319	-0.599	1
2	11.90	10.49	1.41	0.492	0.788	0.040	0.760	2
3	10.80	10.39	0.41	0.986	1.378	8.787	1.521	3
4	10.50	11.99	-1.49	0.751	-1.194	0.286	-1.249	4
5	7.80	8.02	-0.22	0.980	-0.634	1.319	-0.599	5
6	9.70	8.65	1.05	0.919	1.466	1.622	1.670	6
7	5.50	4.45	1.05	0.919	1.466	1.622	1.670	7
8	10.20	9.79	0.41	0.986	1.378	8.787	1.521	8
9	13.40	13.62	-0.22	0.980	-0.634	1.319	-0.599	9
10	8.90	10.49	-1.59	0.492	-0.893	0.052	-0.876	10
11	10.70	12.79	-2.09	0.141	-0.899	0.009	-0.883	11
12	7.60	8.83	-1.23	0.872	-1.378	0.864	-1.521	12
13	5.30	4.63	0.67	0.821	0.634	0.123	0.599	13
14	12.70	12.79	-0.09	0.141	-0.037	0.000	-0.034	14
15	10.60	11.83	-1.23	0.872	-1.378	0.864	-1.521	15
16	7.60	8.83	-1.23	0.872	-1.378	0.864	-1.521	16
17	13.30	12.79	0.51	0.141	0.222	0.001	0.203	17
18	11.60	12.83	-1.23	0.872	-1.378	0.864	-1.521	18
19	19.70	19.03	0.67	0.821	0.634	0.123	0.599	19
20	16.80	12.79	4.01	0.141	1.730	0.033	2.232	20
21	18.30	17.63	0.67	0.821	0.634	0.123	0.599	21

Table F6. 3/16" Zinc Statistical Analysis of Roughness

Sequential Model Sum of Squares

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MEAN	5336.4	1	5336.4		
Linear	53.6	4	13.4	1.580	0.2278
Quadratic	80.9	10	8.1	0.8852	0.5887
Cubic	8.9	2	4.5	0.3891	0.7008
RESIDUAL	45.9	4	11.5		
TOTAL	5525.6	21			

Lack of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
Linear	89.8	12	7.5	0.6523	0.7455
Quadratic	8.9	2	4.5	0.3891	0.7008
Cubic	0.0	0			
PURE ERR	45.9	4	11.5		

ANOVA Summary Statistics of Models Fit

SOURCE	UNALIASED TERMS	RESID DF	ROOT MSE	R-SQR	ADJ R-SQR	PRESS
Linear	5	16	2.91	0.2831	0.1039	223.77
Quadratic	15	6	3.02	0.7104	0.0346	1772.16
Cubic	17	4	3.39	0.7576	-0.2122	

Case(s) with leverage of 1.0000: PRESS statistic not defined.

ANOVA for Quadratic Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	134.4	14	9.60	1.051	0.5092
RESIDUAL	54.8	6	9.13		
Lack Of Fit	8.9	2	4.46	0.3891	0.7008
Pure Error	45.9	4	11.47		
COR TOTAL	189.2	20			

ROOT MSE	3.02	R-SQUARED	0.7104
DEP MEAN	15.94	ADJ R-SQUARED	0.0346
C.V.	18.96%		

Predicted Residual Sum of Squares (PRESS) = 1772.2

INDEPENDENT VARIABLE	COEFFICIENT ESTIMATE	DF	STANDARD ERROR	t FOR H0 COEFFICIENT=0	PROB > |t|
Intercept	15.71	1	1.13	13.85	
A	-1.31	1	1.79	-0.7331	0.4911
B	1.14	1	5.61	0.2029	0.8459
C	-1.62	1	2.14	-0.7581	0.4771
D	-1.27	1	2.14	-0.5919	0.5755
A2	-1.69	1	1.79	-0.9421	0.3825
B2	2.27	1	3.06	0.7403	0.4871
C2	-1.16	1	1.74	-0.6684	0.5288
D2	-0.51	1	1.65	-0.3119	0.7657
AB	0.07	1	4.10	1.78E-02	0.9863

CD	-5.48	1	4.61	-1.189	0.2792

Final Equation in Terms of Actual Factors:

Ra Rough. =

```
            -202.91
  -          2.3933 * Spray Dist
  -         0.23201 * Angle
  +         0.71025 * Current
  +          2.4878 * Pressure
  -         0.18787 * Spray Dist^2
  +       4.480E-03 * Angle      ^2
  -       1.163E-04 * Current^2
  -       5.147E-03 * Pressure^2
  +       1.082E-03 * Spray Dist * Angle
  +       9.624E-03 * Spray Dist * Current
  +       1.872E-02 * Spray Dist * Pressure
  -       2.044E-03 * Angle      * Current
  +       1.817E-03 * Angle      * Pressure
  -       5.477E-03 * Current * Pressure
```

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	OUTLIER t	Run Ord
1	11.12	11.53	-0.41	0.980	-0.958	3.016	-0.951	1
2	14.84	15.34	-0.50	0.492	-0.230	0.003	-0.211	2
3	17.28	17.17	0.11	0.986	0.306	0.435	0.282	3
4	13.21	14.66	-1.45	0.751	-0.958	0.184	-0.951	4
5	18.75	19.16	-0.41	0.980	-0.958	3.016	-0.951	5
6	14.40	13.77	0.63	0.919	0.731	0.403	0.699	6
7	19.10	18.47	0.63	0.919	0.731	0.403	0.699	7
8	14.65	14.54	0.11	0.986	0.306	0.435	0.282	8
9	19.96	20.37	-0.41	0.980	-0.958	3.016	-0.951	9
10	16.13	15.34	0.79	0.492	0.369	0.009	0.340	10
11	13.43	15.71	-2.28	0.141	-0.816	0.007	-0.789	11
12	12.38	12.71	-0.33	0.872	-0.306	0.043	-0.282	12
13	18.07	16.84	1.23	0.821	0.958	0.281	0.951	13
14	13.92	15.71	-1.79	0.141	-0.641	0.004	-0.606	14
15	22.18	22.51	-0.33	0.872	-0.306	0.043	-0.282	15
16	15.84	16.17	-0.33	0.872	-0.306	0.043	-0.282	16
17	21.13	15.71	5.42	0.141	1.933	0.041	2.874	17
18	12.60	12.93	-0.33	0.872	-0.306	0.043	-0.282	18
19	17.69	16.46	1.23	0.821	0.958	0.281	0.951	19
20	12.92	15.71	-2.79	0.141	-0.998	0.011	-0.997	20
21	15.16	13.93	1.23	0.821	0.958	0.281	0.951	21

Table F7. Minitab Analysis for 3/16" zinc.

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MTB > REGRESS C6 20 C1-C5 C7-C21;
SUBC> RESIDUALS C22.
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The regression equation is

CML = 1.98 - 0.177 O - 0.0872 MH +0.000000 BS2 -0.000088 R2 -0.000042 P2
+ 0.0163 O2 + 0.00148 MH2 - 0.60 1/R - 0.62 1/P - 0.729 1/O
+ 38279 1/BS2 + 1.66 1/P2 + 0.228 1/O2

Predictor	Coef	Stdev	t-ratio	p
Constant	1.976	1.177	1.68	0.137
O	-0.1773	0.1453	-1.22	0.262
MH	-0.08723	0.05762	-1.51	0.174
BS2	0.00000005	0.00000011	0.43	0.677
R2	-0.0000878	0.0001367	-0.64	0.541
P2	-0.0000420	0.0001694	-0.25	0.811
O2	0.01628	0.01380	1.18	0.277
MH2	0.0014811	0.0009770	1.52	0.173
1/R	-0.601	1.182	-0.51	0.627
1/P	-0.616	1.696	-0.36	0.727
1/O	-0.7289	0.5876	-1.24	0.255
1/BS2	38279	65762	0.58	0.579
1/P2	1.659	5.652	0.29	0.778
1/O2	0.2282	0.1865	1.22	0.261

s = 0.01217 R-sq = 55.5% R-sq(adj) = 0.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	13	0.0012935	0.0000995	0.67	0.746
Error	7	0.0010367	0.0001481		
Total	20	0.0023302			

SOURCE	DF	SEQ SS
O	1	0.0000666
MH	1	0.0000149
BS2	1	0.0001621
R2	1	0.0000037
P2	1	0.0002897
O2	1	0.0001644
MH2	1	0.0001464
1/R	1	0.0000025
1/P	1	0.0000916
1/O	1	0.0000067
1/BS2	1	0.0000842
1/P2	1	0.0000390
1/O2	1	0.0002218

RESIDUALS:

-0.0057608	-0.0000214	-0.0176417	0.0104644	0.0040351	-0.0047235
-0.0051625	-0.0038292	0.0080923	0.0061976	0.0072918	0.0016620
0.0030909	-0.0052699	-0.0107461	0.0010691	0.0127283	-0.0008567
-0.0013681	0.0038492	-0.0031009			

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13. ABSTRACT (Maximum 200 words)

The U.S. Army Corps of Engineers uses thermal-sprayed zinc and aluminum coatings on hydraulic structures exposed to severe impact and abrasion damage caused by ice and floating debris. These coatings are also used widely for corrosion prevention on civil engineering structures across the nation. An experimental study of the twin-wire electric arc (TWEA) spraying of zinc and aluminum coatings was conducted to demonstrate the suitability of this technology for Army applications.

Experiments on six materials systems were conducted using classical and statistically designed fractional-factorial schemes. TWEA process parameters studied included current, spray angle, spray distance, and system pressure. A systematic design of experiments was utilized in order to display the range of processing conditions and their effect on the resultant coating. The coatings were characterized with bond strength and deposition efficiency tests, and optical metallography. Coating properties were quantified with respect to roughness, hardness, porosity, oxide content, bond strength, and microstructure. Coating performance was evaluated and quantified with erosion testing, and a parameter-property-performance relationship was developed for each materials system.

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